MODERN MARINE ENGINEERING

PART I

THE FIRE ROOM

BY

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MARINE AND MECHANICAL ENGINEER

68 Illustrations

NEW YORK

D. VAN NOSTRAND COMPANY

EIGHT WARREN STREET

1921

Mechanics Dept.

TO

EDWARD J. SMITH, M.D.

OF

BROOKLYN, NEW YORK

PREFACE

The purpose of *Modern Marine Engineering*, of which this book constitutes the first volume, is to reflect present day practice. This book, while primarily intended as a text for schools and colleges, has also been adapted to the needs of the practical man who desires to broaden his knowledge and to advance in his profession.

To the man preparing to qualify for an engineer's license, *Modern Marine Engineering* provides an intensive course planned to fit him for his responsibilities as an engineer officer. It aims to teach the fundamentals rather than to present an assorted collection of questions and answers culled from previous license examinations.

This book should be of value also to the licensed engineer officer. The author has endeavored to present the most recent data, in concise and readable form, with clear and really useful illustrations. The construction detail shown in these illustrations should be especially useful to marine engineering draftsmen, as well as to others engaged in marine engineering construction.

The present volume, I, *The Fire Room*, while essentially a detailed discussion of marine boiler construction, also contains sections on boiler room auxiliaries, boiler corrosion, fuels and combustion. General theory, including definitions, calculations, steam tables, etc., has been reserved for the final chapter.

The framework of this book is derived from the marine

engineering course given during the world war, by the U. S. Navy Steam Engineering School at the Stevens Institute, Hoboken, N. J. The data on marine boiler construction were obtained at first hand through studies and observations made at various boiler factories. Most of the sketches contained in *Modern Marine Engineering* were made by the author while at these factories, with the exception of those on boiler room auxiliaries, which he made while on shipboard.

HARRY G. CISIN

January 7, 1921

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MODERN MARINE ENGINEERING

LESSON 1 — BOILERS

1. A boiler is any vessel used to generate steam and hold it under pressure

It must have the following three essentials:

(*a*) A vessel for the water.
(*b*) Space to generate heat.
(*c*) Metallic surface to separate the hot gases from the water.

2. Classification of Boilers

(*a*) Fire tube.
(*b*) Water tube.

3. Fire Tube Boiler

One in which the hot gases pass through the tubes and the water surrounds the tubes.

4. Water Tube Boiler

One in which the water passes through the tubes and the hot gases surround the tubes.

5. Characteristics of Fire Tube Boilers

(*a*) Slow steamers — slow in getting up steam.
(*b*) Large quantities of water.
(*c*) Furnaces within the shell.
(*d*) Gases pass through the tubes.

6. Types of Fire Tube Boilers

(*a*) Scotch or return tube (Fig. 1):
(1) Single ended.
(2) Double ended.

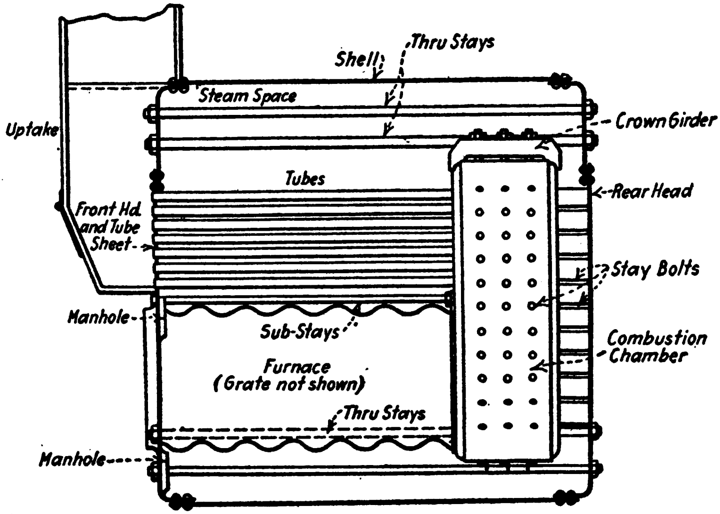


FIG. 1. Longitudinal Cross-section of Two Furnace Boiler

(*b*) Direct:
(1) Locomotive.
(2) Gunboat.

7. Advantages of Scotch Boiler

(*a*) *Less fluctuation in steam pressure.* Due to the large volume of water, if there is any tendency for the pressure to drop, more steam will immediately be formed. Another reason for small fluctuation is that, due to the construction of the Scotch boiler, there is a large steam space, which acts as a reservoir.

(*b*) *Require less attention to fire.* Since the furnaces and combustion chambers are separate, opening the door of the furnace does not affect the boiler as much as in the case of a water tube boiler.

(*c*) *Requires less attention to the water.* This is due to the larger volume of the water. The danger of a dry boiler is reduced. One water tender can take care of 12 Scotch boilers while he could not take care of more than two or three water tube boilers.

(*d*) *Less radiation losses.* Since the furnaces are within the shell, the hot gases of combustion do not come in contact with any surface which is not surrounded with water until they come to the uptake.

(*e*) *Fewer joints.* The Scotch boiler is a rigidly constructed boiler, with all the parts securely fastened and braced. There are a few hundred parts in the Scotch boiler, whereas there may be a few thousand in the water tube boiler. There are 13 manhole plates in a double ended Scotch boiler while there are 700 handhole plates in the front and back headers of a B. & W. water tube boiler.

(*f*) *Less danger from salt feed.* It may be necessary to use

salt water. This can safely be used in a Scotch boiler, with the proper precautions, as there are no small spaces between the furnaces, shell and back heads.

(*g*) ***Easy to examine and clean.*** The manholes are large enough to allow a man to climb through and clean off the surfaces. The water sides must be kept clean for economy and for the sake of the boiler itself. If scale is allowed to form, heat will be lost, and also the tubes will become overheated.

8. Disadvantage of Scotch Boiler

In case of a rupture, the large volume of water (say 30 tons) would insure a great increase in the volume of steam, due to the reduced pressure and this would mean a violent and disastrous explosion.

9. Features of Scotch Boilers

(*a*) ***Path of gases.*** The gases are generated on the fuel bed and pass on to the combustion chamber where the combustion is completed; their direction is then reversed and they pass back through the tubes and to the uptake and stack.

(*b*) ***Water circulation.*** This is very indefinite. The ideal circulation would be down next to the shell and then up around the furnaces and around the tubes.

(*c*) ***Slow steamer.*** All the joints in the Scotch boiler are rigid. The plates are made strong enough to withstand only certain pressures, and due to the rigid construction it will not stand forcing or rapid methods of getting up steam. It should take from six to twelve hours to raise steam from cold water to the working pressure.

(*d*) *Types of furnaces.* Since the cylindrical shell has more strength than flat surfaces, the cylindrical furnace is the one always used in Scotch boilers. The most common type is the corrugated furnace. Due to the different curvatures of the corrugated furnace, pressures are exerted in different directions, thus taking care of the expansion and contraction.

QUESTIONS

1. What is a boiler?
2. Name three essentials in the make up of every boiler?
3. How may boilers be classified?
4. Define a fire tube boiler.
5. Define a water tube boiler.
6. Name four characteristics of fire tube boilers.
7. What are the important marine types of fire tube boilers?
8. Name seven advantages of the Scotch boiler.
9. Name a disadvantage of the Scotch boiler.
10. Give some of the important features of the Scotch boiler, with special reference to the path of the gases, the water circulation, time taken to get up steam, and the usual type of furnace.

SKETCHES

1. Sketch from memory a longitudinal section of a Scotch boiler.

LESSON 2 — CONSTRUCTION OF THE SCOTCH BOILER

1. Shell (Fig. 2)

(*a*) *Parts*. The shell is cylindrical in form, and is made up in plates, each plate being rolled to form before being put

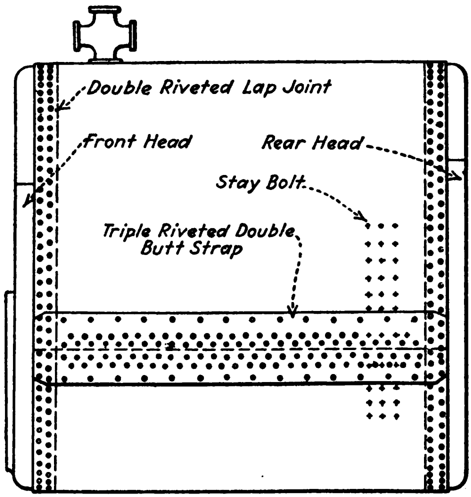


FIG. 2. Side View of Scotch Boiler

into place. Open hearth mild steel is used, with a tensile strength of from 60,000 to 80,000 pounds per square inch. Usually when the plates reach the shop, they have the approximate shape into which they will be cut. This obviates the necessity of doing much chipping in the shop. If the plates are not of the right size, they are first cut down

with an acetylene torch, and then the rough edges are trimmed with a chipping tool.

(*b*) *Circumferential seams.* The plates for the shell are laid out, and the holes for the circumferential seams are drilled. The pilot holes for the longitudinal seams are also drilled at this time. Two or three plates, placed one on top of the other, can be drilled at the same time. A template is used

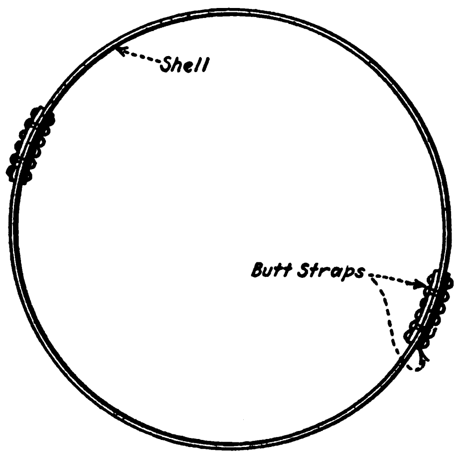


FIG. 3. Section through Shell of Scotch Boiler Showing Butt Straps

to mark the top plate. The plates are then bent and fastened together by means of the pilot bolts. The circumferential seams (those around the boiler) are commonly secured by lapping over one plate upon another, using double or triple riveting. Where the two plates come together they are planed down to get a good joint.

(*c*) *Longitudinal seams.* The longitudinal seam is made a butt seam because there is an immense stress upon it. It is

subjected to twice the stress of the circumferential seam. The butts for the longitudinal seams are all drilled first. After the butts are fitted on to the shell, the holes for the longitudinal seams are drilled in the shell, using the holes in the butt strap for guides. (In the butt joint (Fig. 3) the ends of the shell butt together and a butt strap is used to

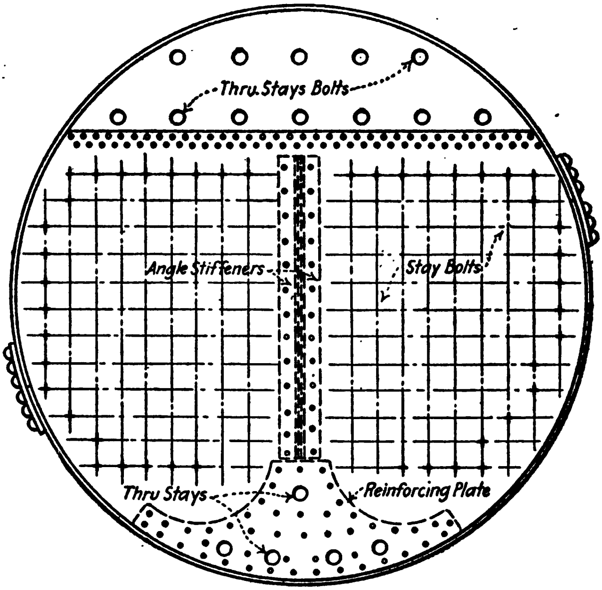


Fig. 4. Sketch of Rear Head

hold them in place.) The longitudinal joints are usually double butt, triple riveted. After the holes for the longitudinal seams are drilled, the shell is taken down, and the burrs on these holes are cleared off. The shell is then reassembled and the longitudinal joints are riveted by means of the hydraulic riveter.

2. Back Head

(*a*) *Parts.* The back head (single ended boiler) (Fig. 4) is put in next. It is made of two plates, rolled and cut to the proper circumference. The plates are flanged. The edge is turned on the head, never on the shell. In fitting

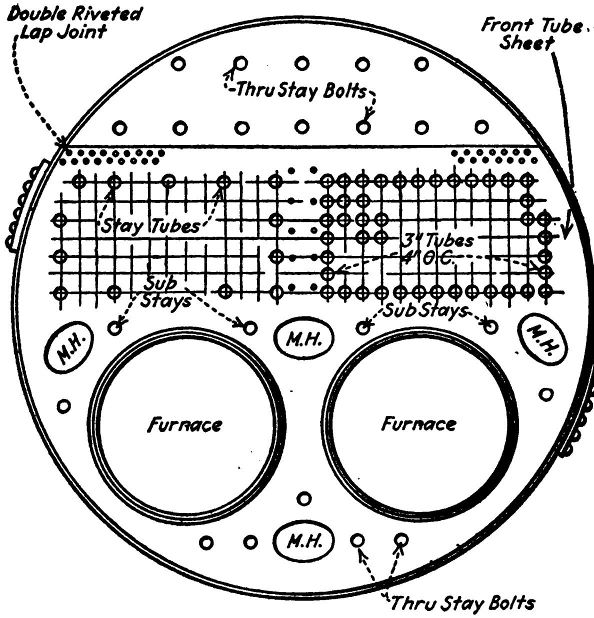


FIG. 5. Sketch of Front Head

the back heads in place, previous to riveting, they are held in place by means of pilot bolts. Back heads are usually flanged in, although they are sometimes flanged out, in which case both ends of the rivets are outside the boiler.

(*b*) *How fastened.* A double riveted lap joint is the common

one used, the riveting being done by means of a hydraulic riveter (bull riveter). After riveting the seam is caulked. In drilling the holes in the heads, the holes in the shell are used for guide holes and every fourth hole is used as a pilot hole. In making the flanges, the edges of the plates are

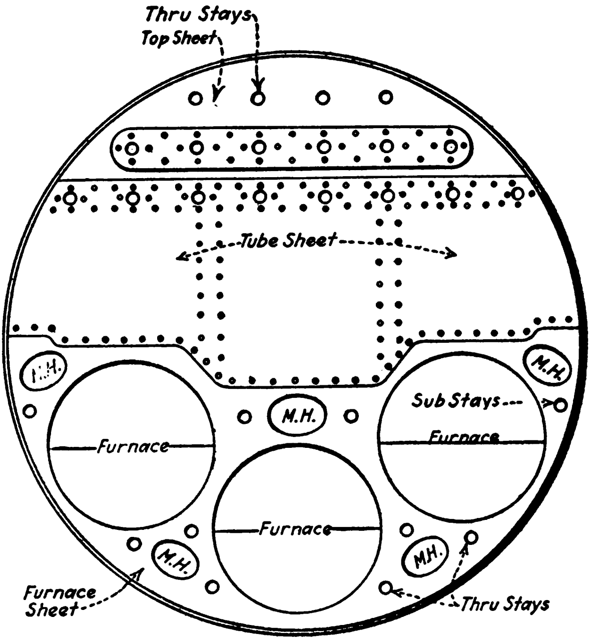


FIG. 6. View of Front Head Three Furnace Boiler

heated and the flanging is done in a hydraulic press after which the two pieces comprising the back head are bolted together and hammered to fit, as tested with a template.

3. Front Head

(*a*) *Parts.* The front head is usually made in three parts (Fig. 6). In the smaller size boilers, the front head may be

in two parts (Fig. 5) or even in one part. In all sizes, the parts of the front head are usually joined by double riveted lap joints. Where the head is divided into three parts, these are:

(1) *The top head sheet.* This has the stay openings, manhole, and boiler fitting openings. The top sheet is reinforced along the row of through stays by an outside stiffening plate. Where the top sheet and the tube sheet

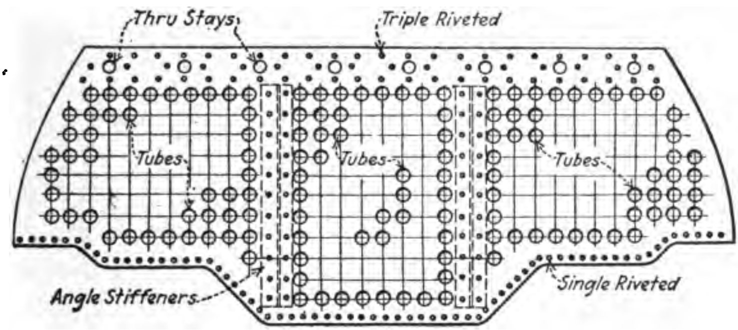


FIG. 7. Sketch of Front Tube Sheet

overlap, a row of stays is placed, thus taking advantage of the two thicknesses of metal.

(2) *The middle head sheet or front tube sheet* (Fig. 7). The tube sheet has openings for the common tubes and stay tubes and also for the stay bolts. The use of a separate sheet for the tubes facilitates removal, since otherwise it might be necessary to take out the front head. The tube sheet is made of low carbon steel. In a common type of three furnace boiler the tube sheet is $\frac{3}{4}''$ thick. In this boiler the top sheet and furnace sheet are $\frac{7}{8}''$

thick. The tube sheet may be made thinner since it receives extra support from the common and stay tubes. It is also stiffened by the use of two sets of angle irons. The usual tensile strength of the tube sheet is about 60,000 pounds per square inch.

(3) *The lower head sheet or furnace sheet.* The openings for the furnaces, manholes, handholes, and stay bolts are in this sheet.

(*b*) *Method of construction.* When the sheets are received in the boiler shop, they are rectangular and flat. While the sheets are flat, all holes for the tubes and stay bolts are drilled. A template is always used in laying out the sheets. The tube holes are drilled slightly undersize. After the holes are drilled, the sheet is cut to shape and flanged. The same procedure is followed in the construction of the top sheet. The front head is flanged in. In making the furnace sheet, the outer edges are flanged first. The furnace openings are laid out next, by two circles each, the inner one for burning and the outer one for flanging. The openings are heated one at a time, and a die comes down, first with a conical thrust and then with a cylindrical thrust. The flanges are turned outward. The manholes are made next, and in the same way, except that the flanges are turned in, and all are done at one time. Before riveting the three sheets together, rivet holes are drilled in the tube sheet and this is fastened to the top sheet and furnace sheet by means of a few pilot bolts, and the front head is fitted to the shell. The rivet holes in the tube sheet are then used as guides for drilling the holes in the other sheets. Before the sheets

are finally riveted together, they are separated and the burrs are removed from the drilled holes. They are then riveted together before the head is put into the shell, the top sheet being fastened to the tube sheet by a double or triple riveted lap joint, and the furnace sheet being fastened either by a double or a single riveted lap joint. After the front head has been replaced in the shell, rivet holes are drilled in the flange, using the shell rivet holes as guides. The front head is then riveted to the shell by hand, being fastened by a double riveted lap joint. After the front head has been fitted to the shell, the undersize tube holes are drilled to full size for the common tubes, and the stay tube holes are tapped out. The furnaces are riveted to the furnace sheet by hand.

The stays, sub-stays, stay tubes and common tubes are next put in.

4. Bracing

Supporting stays for flat surfaces are of the following types: (*a*) *Through stays.* These stays, sometimes called *end-to-end braces* pass from the front to the back heads, thus supporting the back head and the top and bottom front head sheets (see Fig. 8). According to Seaton, the spacing of the through stays, bracing plates not exposed to the direct action of the hot gases, should never be less than 14″ center to center. This is necessary, in

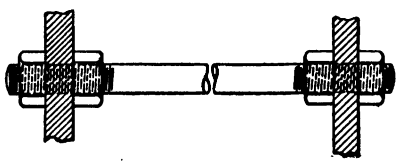


FIG. 8. Through Stay Bolt

order that a man can pass between them. They are usually placed on from 15″ to 17″ centers.

(*b*) *Stay bolts.* These are any bolts used to tie combustion chambers together, or to the rear head. They are generally some form of *screw stay.* They are made of wrought iron or mild steel, especially made for use as stay bolts. The tensile strength of the iron should never be lower than 45,000 pounds per square inch, the steel not less than 55,000. It is necessary that all boiler braces and stays be made of the same grade as the best material used for stay bolts.

(*c*) *Screw stays or screw stay bolts.* These connect the plates of one combustion chamber to another; the plates of the combustion chamber to the back head, and also to the shell of the boiler. Both ends are threaded so that they can screw through the plates at each end. Nuts are usually fitted at the ends, although in some cases the ends are riveted over. Nuts which are exposed to the direct action of the intense heat are made of steel, while all others are made of iron. The stay bolts are often threaded for their entire length although this is not considered the best practice.

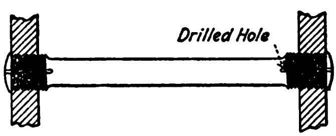


FIG. 9. Stay Bolt

Stay bolts often break, due to the unequal expansion of the plates into which they are screwed. They are sometimes drilled at each end (see Fig. 9) so that if the bolt breaks the steam or water will blow out through the small hole, thus giving warning of the break.

(*d*) *Sub-stays* (Fig. 10). These run from the front tube

sheet to the front sheet of the combustion chamber, being fastened to the combustion chamber by means of pads.

(*e*) *Gusset stays* (Fig. 11). Gusset stays are made from plates and angles. The top of the combustion chamber is sometimes secured to the back head of the boiler by gusset stays. In double ended boilers, two combustion chambers may be tied together in this way. Gusset stays are also used between the top head sheet and the shell and between the top back sheet and the shell.

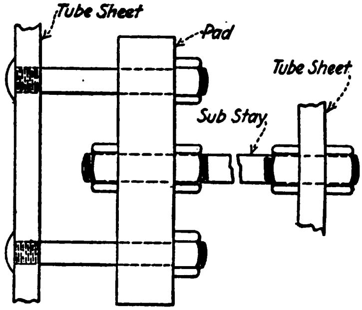


FIG. 10. Sub-stay Bolts

(*f*) *Flanged foot braces.* These run obliquely between the furnace sheet and the shell and one end is flanged over in order to secure a perfect fit.

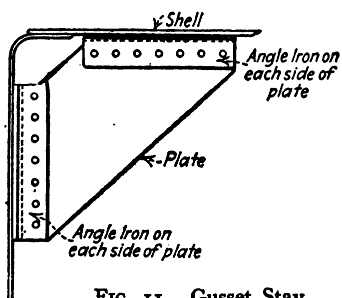


FIG. 11. Gusset Stay

(*g*) *Oblique braces.* These are braces which run at a small angle, in order to connect parts which need to be supported with convenient points of support. Wedge shaped washers are necessary under the nuts.

(*h*) *Forked end braces.* They are forked at one end. Hence this end can be fastened at two points and the load is thus sub-divided.

(*i*) *Girder stays* or *crown bars*. These are also called *bridge* or *dog stays*. They are made by bolting, or more usually riveting, two steel plates together, keeping them at the proper distance apart by means of distance pieces. Stays which are bolted to the top of the combustion chamber, pass up between the steel plates, transferring the load through caps to these plates, which in turn are supported by the edges of vertical plates forming the front and back of the combustion chamber.

5. Tubes

There are two kinds of tubes in the Scotch boiler, *common tubes* and *stay tubes*.

(*a*) The *common tubes* (Fig. 12) are first set into the boiler with about $\frac{5}{16}''$ projecting over the ends of the tube sheets. They are then expanded into each sheet and next are beaded over, sometimes only at the rear tube sheet, and sometimes at both front and rear sheets. The beading serves to protect the ends of the tubes from the hot gases. In some cases the tube sheet is recessed out for the beaded end of the tube. The front ends of the tubes are generally made a bit larger than the rear ends, for easier removal. The metal is about 0.16″ in thickness. The common tubes are made of a good quality of homogeneous iron, usually a charcoal iron, and are lap welded. The working test for these tubes is

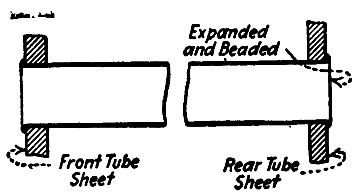


FIG. 12. Common Tube

that they should show no flaw when expanded into the tube sheet and beaded.

(*b*) The *stay tubes* (Fig. 13) are stronger than the common tubes, being made of extra heavy metal of about $\frac{1}{4}''$ thickness and they are specially fitted to the tube sheet by screw joints so that they can act as stays between the tube sheets. Depending on the thickness of the tube sheet, the percentage of the stay tubes to the total number of tubes in the boiler vaires from 20 per cent to 30 per cent. When stay tubes are fitted, it is usual to bead over only the back ends of the common tubes. If, however, no stay tubes were fitted, it would then be absolutely necessary to bead over both ends of the common tubes in order to properly support the tube sheets. The stay tubes are often made of cold drawn seamless steel. They are a bit larger in outside diameter than the common tubes. For example, a common size met with is a $3''$ diameter common tube and a $3\frac{1}{2}''$ diameter stay tube. Since the stay tubes are too heavy to be rolled at the ends, the edge of contact between them and the head is caulked.

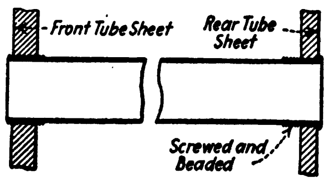


FIG. 13. Stay Tube

(*c*) *Ferrules.* These are small cast iron pieces placed at the rear ends of tubes used under forced draft, to further protect the tube ends. In certain boilers the ferrules are used only in the stay tubes. In other boilers they are used in the back ends of all the tubes. They are forced into proper position by tapping with a hammer. The internal diameter of the

ferrules varies from $1\frac{1}{2}''$ to $1\frac{3}{4}''$. The purpose of having the rounded part of the ferrule cover over the beaded end of the tube is to prevent the heated gases from acting directly upon the joint there. The heat is conducted past this point to a part of the tube surrounded by water. If the end of the ferrule should be burned off, it is possible to renew the ferrule again. Care should be taken not to push out the ferrules when cleaning the tubes with brushes. If an ordinary tube has been expanded until its thickness is much reduced, the use of a straight ferrule serves to strengthen it temporarily.

(*d*) *Retarders.* These are made of thin sheet steel, of the same width as the internal diameter of the tube. They are twisted before being pushed in the tubes and they are supposed to impart a rotary motion to the gases.

(*e*) *Arrangement of tubes.* Tube sheet holes are always drilled in vertical and horizontal rows with the greater spacing between the vertical rows. Such an arrangement gives greatest chance to clean the tubes on the water side, and it is also supposed to give better circulation.

6. Furnace

(*a*) *How made.* Furnaces are made of cold rolled lap welded steel. The corrugations are made by placing the furnace in a vertical producer gas furnace until uniformly heated all over. The corrugations are rolled in the furnace, while hot, by means of two rollers. This is done with the furnace in a vertical position. After the corrugations have been put on the furnace, it is left on end and allowed to cool. Great care must be taken to prevent unequal cooling. Some furnaces have a horse collar flange on the end which connects

to the combustion chamber. This flange is put on in a separate operation, after the furnace has cooled. A mandrel and a hydraulic former are used and the operation is finished off by hand with a hammer. A test hole is next drilled in the furnace to see if it is of the required thickness, and if so it is ready to be put on the boiler. The steel used for the furnaces is low carbon, open hearth steel, being usually about $\frac{5}{8}''$ thick. The furnace may be made slightly thinner or thicker, depending upon the quality of the steel and the pressure to which the boiler is to be subjected. The steel used has a tensile strength of from 55,000 to 65,000 pounds per square inch. The smallest internal diameter is usually about 36″. It is customary to alternate the corrugations of adjoining furnaces. In order that it may be possible to remove the furnace, if necessary, the straight part at the rear has a smaller diameter than the corrugations. The straight part of the furnace at the front has a larger diameter than the corrugations so that the furnace can enter into the furnace hole in the lower sheet of the boiler. In some cases, furnaces are made non-removable.

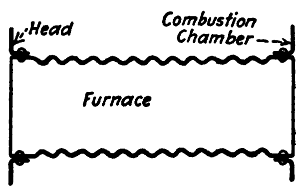


FIG. 14. Sketch of Furnace Showing Connection to Head and Combustion Chamber

(b) *Method of securing.* The furnace is secured to the combustion chamber by a lap joint, with a single row of rivets, the combustion chamber being flanged to receive it. It is secured to the furnace sheet of the front head in the same manner, with a single row of rivets, the flange being on the furnace sheet (see Fig. 14).

(*c*) *Types.* The cylindrical furnace is the only kind used in fire tube boilers. It is not as efficient as the rectangular type, since the space above and below the grate is limited but it is cheaper and easier to construct. It is made with only two joints, one at each end, and as it requires no stays, there is no difficulty in cleaning the boiler around the furnaces. In the earlier types of furnaces, several short cylinders were riveted together to form the furnace. The rivets passed through flanges turned on the ends. Between the flanges an "Adamson Ring," was fitted in order to stiffen the furnace. Increasing pressures required either a furnace too thick for practical purposes, or else a new design. This resulted in the construction of the Fox Corrugated Furnace. This was later superseded by the Purves Ribbed Furnace and finally by the Morison Suspension Furnace, which combines the best points of the Fox and Purves furnaces, and is considered as the standard for fire tube boilers.

(1) *Fox corrugated furnace.* This type has small corrugations spaced about 6″ between the tops. These corrugations extend the same amount above and below the mean diameter of the furnace. All parts of the furnace have the same thickness. The Fox furnace is liable to crack at the bends, due to the fact that the hollows on the water side collect deposits which are hard to remove and these are just at the part of the furnace nearest to the fire. As a result overheating takes place and this is often followed by cracking.

(2) *Purves furnace.* This furnace has strengthening ribs

in the water space and hence there are no hollows for the collection of deposits. The flat parts, between the ribs, are weak, however, and these are likely to sag. Moreover, the furnace is not of uniform thickness, due to the ribs, and for this reason the strength is not uniform.
(3) *Morison furnace.* The Morison has corrugations, but the outward corrugations are shorter and serve the purpose of stiffening the furnace, while the inward corrugations are suspended between them and can be made longer, thus avoiding the small hollows of the Fox type.

7. Grates

(*a*) *Shape of bars.* Cast iron bars are shaped as shown in Fig. 15. They may be cast either single or double. The double bar is the common one, the single bar being used in case the double ones do not exactly fit the grate width. The side bars, sometimes referred to as Wing bars, are so shaped as to fit the corrugations closely. Wrought iron and steel bars are made thinner than the cast bars, two or three being riveted together in order to give greater stiffness.
(*b*) *Support.* Where the bars are in two lengths, one end of the front bar rests on the dead plate and the other end on a bearer bar. The rear bar also has one end on the same bearer bar, while the other end rests on the bridge wall. In some cases there are three lengths, in which case two

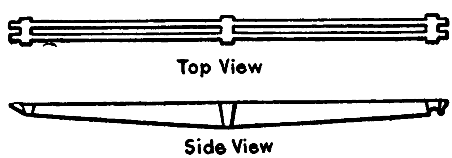


FIG. 15. Sketch of Grate Bar

bearer bars are necessary. Lugs which are riveted or bolted to the furnace hold these bars. The bars are made heavy enough to support the load, and in some cases are double.

(*c*) *Slope of grate.* The grate inclines downward, from the front to the back, the usual slope being 1″ in 18″.

(*d*) *Air spaces.* The bars, when put in close together are so made, that they have air spaces between them. The air spaces constitute about 25 to 30 per cent of the entire grate surface.

(*e*) *Cooling of bars.* Cast iron bars have grooves on their top surface in which ashes collect. The purpose is to make the ashes form a barrier for protection of the top of the bar from the intense heat, and incidentally to reduce the forming of clinkers.

(*f*) *Limiting features of length.* The length of grate which can be conveniently fired is the determining factor in the design of the grate length. Six feet is an average length, two lengths of bars being used.

(*g*) *Reducing grate area.* This is sometimes done, when the supply of coal is low, by covering the back of the grate with ashes. The grate area is often reduced thus, for cruising.

8. Furnace Front and Doors

(*a*) *Construction of furnace front* (Fig. 16). The furnace front consists of a steel plate (in some cases two plates bolted to each other) bolted to the furnace sheet, the bolts being riveted over on the inside of the boiler. The furnace front closes the opening of the furnace above the grate and carries the furnace door.

(*b*) ***Hinged door.*** This type is found on practically all the older types of fire tube boilers. It is sometimes called the "Open Type Door." One type of hinged door has four liners with alternately arranged perforations. The door may be made to swing closed by gravity, if the axis on which it is hinged forms an angle with the vertical. This is usually accomplished by setting the lower hinge farther away from

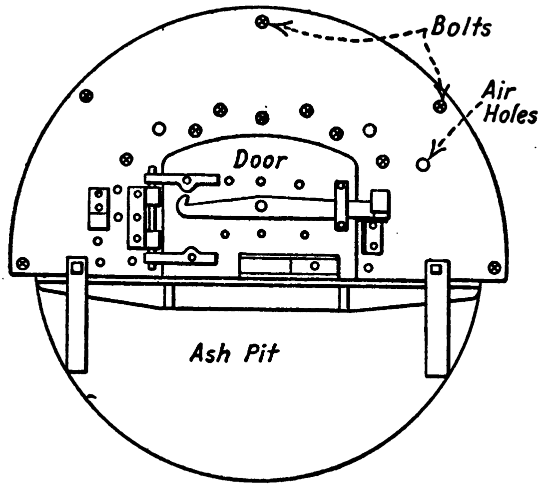


FIG. 16. Furnace Front

the furnace front than the upper one. A catch fastened to the furnace front is arranged to hold the door closed. By lifting a cam handle the catch can be unfastened. Another type of door is shown in Fig. 16. It is made of cast iron and has but one liner. It is hinged to the furnace front as shown, is fitted with a sliding air regulator and has a number of small holes for admitting air. The circulation of air between the door and the liner tends to keep the door cool.

(*c*) *Balanced door* (Fig. 17). In this type the door is hinged at the top rather than at the sides. To open the door, it must be swung inwards. A weight is fitted on the outside, which acts as a counter-balance. Modern coal burning and coal-and-oil-burning boilers are, in general, all fitted with balanced doors. When the door is closed, the counter-weight is closest to the boiler. An increase of pressure in the furnace, due to a burst tube will cause the door to close automatically, thus safe-guarding the firemen.

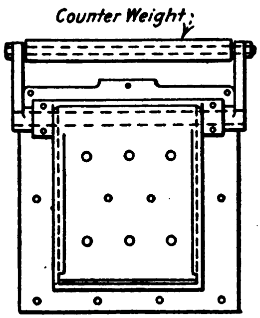


FIG. 17. Balanced Type Door

(*d*) *Liners* (Figs. 18 and 19). The furnace front, furnace doors, and even the slicing doors are fitted with liners to protect them from the direct heat of the furnace. The furnace front liners usually consist of steel sheets which are bolted to the furnace front. The door liner is either of sheet steel

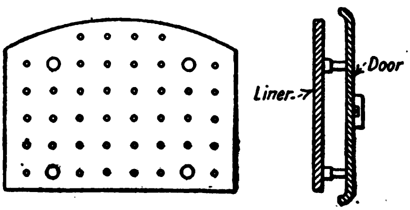


FIG. 18. Door Liner

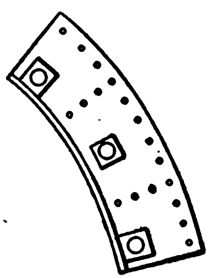


FIG. 19. Section of Furnace Liner

or of cast iron, and fastened to the door by means of bolts. When the liners burn out, they can be replaced.

(*e*) *Dead plate.* The dead plate may be a cast iron fitting, fastened to the furnace by means of lugs and studs (Fig. 20). In some cases it is carried on an angle iron support, while in others it is simply an extension of the bottom of the door frame which extends back a short way and then drops a bit to form a shelf for the front ends of the grate bars. The purpose of the dead plate is to support the front ends of the grate bars, and also to provide a space upon which soft coal, when first fired, may be piled, thus providing for the gradual distillation and combustion of its gases.

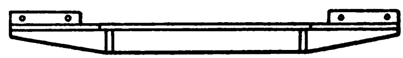


FIG. 20. Dead Plate

(*f*) *Air holes.* The furnace front has a small number of air holes for providing air above the grate. There are a larger number of air holes in the liners. These are smaller in size than the holes in the furnace front and alternate so that the air will circulate between the liners and the front. The air is thus heated before it leaves the inner liner. Considerations of economy sometimes necessitate the omission of holes in the furnace doors, and there are a good many different ways of placing the holes for the admission of air. Specially designed fittings are necessary to adapt the furnace doors for use with forced draft. A sliding air regulator is sometimes fitted in the furnace door to regulate the supply of air above the grate.

(*g*) *Air dampers.* These are more often referred to as *Ash Pit Doors* and are used to close the portion of the furnace below the grates. The ash pit door is made of thin sheet steel, fitted with lugs on the inside and handles on the out-

side. The lugs slip over a bar fastened to the furnace and this serves to hold the door in place.

(*h*) *Slicing door.* A small hinged door, opening downward, and held by a catch, is sometimes provided in the furnace door for the purpose of slicing the fire without opening the furnace door. In some cases the slicing door opens upwards, while in others there is simply a small opening at the bottom of the furnace door which may be closed by means of a sliding door (Fig. 16).

9. Bridge Wall

(*a*) *Purpose.* The purpose of the bridge wall is to limit the extent of the fire and also to produce a more complete mixture of the gases in the combustion chamber. The latter effect is obtained by the reduction of the opening at the back end of the furnace, which results in a speeding up of the gases.

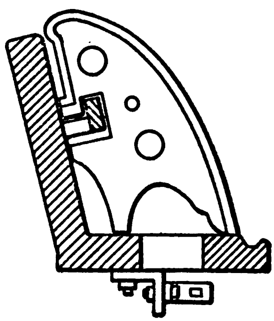


FIG. 21. Sketch of Bridge Wall Segment (Wager Patent)

(*b*) *Cast iron bridge wall.* This is the more modern type. Such a bridge wall is the "Wager Patented" type (Fig. 21). It consists of cast iron segments which are hooked on to a transverse support bar. The castings are fitted with holes and distance lugs, for the purpose of allowing the passage of air, for cooling and for aiding combustion. The ashes which collect also aid in the cooling of the castings.

(*c*) *Brick bridge wall.* There are a variety of designs of

brick bridge walls. One type consists of a cast iron fitting at the back of the furnace and fastened to the furnace sides. This serves to support the back ends of the grate bars and also as a support for a built up wall of fire brick. The height of this brick work will determine the amount of the

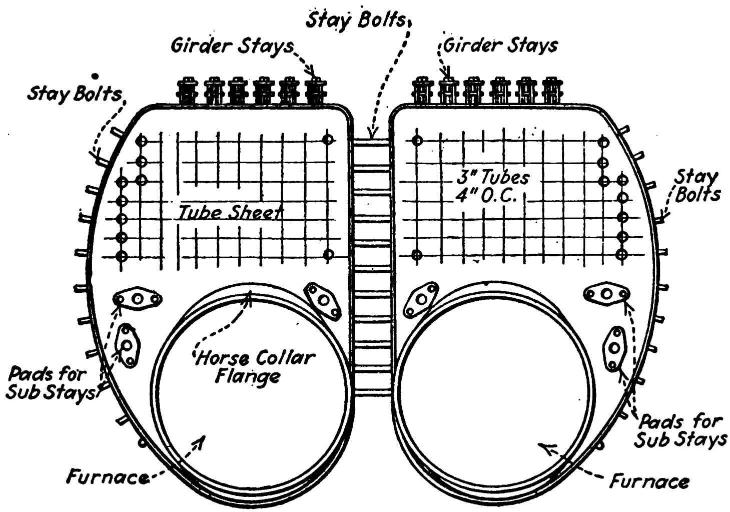


FIG. 22. Front View of Combustion Chamber

speeding up of the gases. The brick wall consists of ordinary fire brick laid with a thin layer of fire clay.

(*d*) *Support for grate bars.* As mentioned above, the bridge wall supports the back ends of the grate bars.

10. Combustion Chamber (Figs. 22 and 23)

(*a*) *Purpose.* The purpose of the combustion chamber is to provide a space in which the partly burned volatile gases, driven from the coal, can combine properly with the oxygen

brought in with the air through the hot fuel bed. Thus the combustion is completed and the gases expand before passing back through the tubes.

(*b*) *Types.* There are a great variety of methods used in the construction and also in the number of combustion chambers used. In a three furnace boiler there may be three separate combustion chambers or there may be a single combustion chamber for the three furnaces. The present tendency is toward separate chambers although there seems to be an advantage in the fact that the single combustion chamber provides a larger space for the combustion of the gases. A four furnace boiler (single ended) may have two combustion chambers, or there may be four separate combustion chambers, or in some cases the two inside furnaces have one combustion chamber and each outside furnace has a combustion chamber. In double ended boilers, the combustion chambers of each end are now always made separate. In some cases the top of the combustion chamber is rounded and in other cases it is flat. The latter type gives a larger space for the tubes and a bigger combustion chamber and is the one usually used.

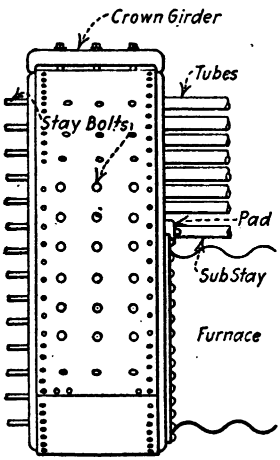


FIG. 23. Side View of Combustion Chamber

(*c*) *How constructed.* The combustion chamber is usually

made of low carbon steel, having a tensile strength of 55,000 pounds per square inch. The bottom plate is usually made $\frac{7}{8}''$ thick while the other plates of the chamber are about $\frac{5}{8}''$ thick. The combustion chamber is constructed of steel plates riveted together by means of lap joints. In one method of construction there are six sheets to the combustion chamber. These comprise the top or crown sheet, two side or wrapper sheets, the front sheet or back tube sheet, and the bottom sheet. In another type there are only four sheets, the crown sheet and the wrapper sheet being combined as one. The wrapper sheets are planed up the same as the shell sheet. The stay and rivet holes are drilled while flat. These sheets are shaped cold in a hydraulic press. The wrapper sheet is used as a template in drilling the rivet holes in the flanges of the front and back sheets. The front and back sheets are connected to the rest of the combustion chamber with a single riveted lap joint. The other parts of the combustion chamber are put together with double riveted lap joints. The holes for all stays are drilled while plates are flat. The tube holes are also drilled before flanging. The top, bottom, and wrapper sheets are first riveted together. The back sheet is then flanged and fitted to the side, and then both these are drilled and riveted with a bull riveter. In flanging the front and back sheets of the combustion chamber, the corners are heated and the other parts are flanged cold. The back tube sheet is flanged next and fitted to the rest of the chamber. Before doing this a manhole is cut out of the sheet, where the furnace will enter, so that a man can go inside to hold on, when riveting this

sheet to the rest of the chamber. Then the hole for the furnace is cut out by means of an acetylene burner. The furnace is then fitted, the holes are drilled, and it is then riveted to the chamber.

(*d*) *Method of staying.* Since the bottoms of the combustion chamber are semi-circular and of rather thicker plate than the rest of the chamber, stays are not required there. The combustion chamber rests on one or more angle iron frames fastened to the boiler shell, but not to the chamber. The sides and back of each combustion chamber form large flat surfaces which are stayed by means of screw stays. The front sheet receives support, not only from the tubes, but also from sub-stays. Girder stays support the crown sheet.

11. Manholes (Fig. 24)

(*a*) *Shape, number, and size.* The manholes are elliptical openings in the head and shell, placed there to allow for the entrance of a man, for cleaning and inspection of the interior surfaces. The number of manholes varies with the size of the boiler and the number of furnaces. In a four furnace double ended boiler there are usually thirteen manholes; six in each head and one in the shell. In a three furnace single ended boiler, there may be two manholes in the furnace sheet and one in the shell; or there may be three, four, or even five manholes in the furnace sheet and one in the shell. The manhole in the

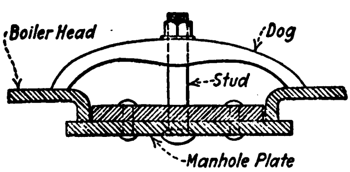


FIG. 24. Cross-section of Manhole Showing Cover in Place

shell is near the top. The standard size manhole is 11″ by 15″.

(*b*) *Construction.* In making the manhole, the sheet through which the hole is cut is sometimes flanged inwards, the edge or face being finished by planing to receive the manhole plate (Fig. 25). In some cases, the manhole is cut out of the sheet without flanging the latter. In this case, a *stiffening ring* is riveted to the sheet, around the hole. The stiffening ring is sometimes used, even though the sheet is flanged (Fig. 26).

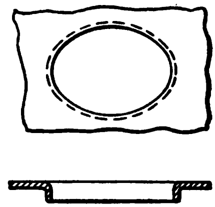


FIG. 25. Manhole

(*c*) *Manhole plates* (Fig. 27). The plates close the manhole. They may be flat or dished. Special dogs, fitted with studs and nuts hold the plate in place against the manhole. A gasket intervenes between the planed edge of the manhole and the plate. The plate bears against the inside of the sheet, so that the pressure tends to keep the joint tight. In some cases, handles are riveted to the outside of the plate. The plate or cover is made up of steel plates, built up and riveted together. Figure 27 shows a common type, made up of two sections, the smaller one riveted to the larger by countersunk rivets. The smaller plate here acts as a reinforcing plate. The studs, fastened to the dogs, are put into the plate while it is hot, and then the plate is allowed to cool. The dogs are

FIG. 26. Section of Manhole Showing Stiffening Ring

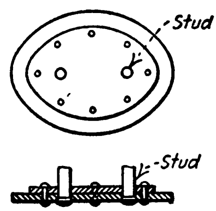


FIG. 27. Manhole Plate

usually pressed from sheet steel, although sometimes they are forged.

(*d*) *Gaskets.* The purpose of the gasket is to make the joint between the manhole and the plate steam tight. First of all, the metal surfaces must be carefully fitted together. Next a gasket of asbestos cardboard, fiber sheet, rubber, or like material which will give, is placed on the manhole plate so that it lies on the fitted surface. It is necessary to cover the plate surface with red or white lead and the boiler side of the gasket with black lead and chalk, so that the gasket will stick to the plate and not to the boiler. Gaskets for the various shaped manholes are often made from metal templates, kept on hand for this purpose. Where the gasket cannot be cut out in one piece, it is necessary to cut the ends sloping, so that they will fit over one another and they are then sewed together with twine. The gasket should be about $\frac{1}{8}''$ thick, although it may be made thicker with a poorly fitting plate. The gasket is first put on the manhole plate, care being taken to obtain an accurate fit. The plate is then inserted in its proper place in the manhole.

12. Uptakes (Figs. 28 and 29)

(*a*) *Location.* The uptake is located between the smoke box and the funnel. The hot gases coming from the tubes, pass through the smoke box or front connection, then through the uptake, to the smoke pipe or funnel. If possible the uptakes are made without sharp turns so that the gases may have an unrestricted passage to the funnel.

(*b*) *Number.* Each boiler or group of boilers has an in-

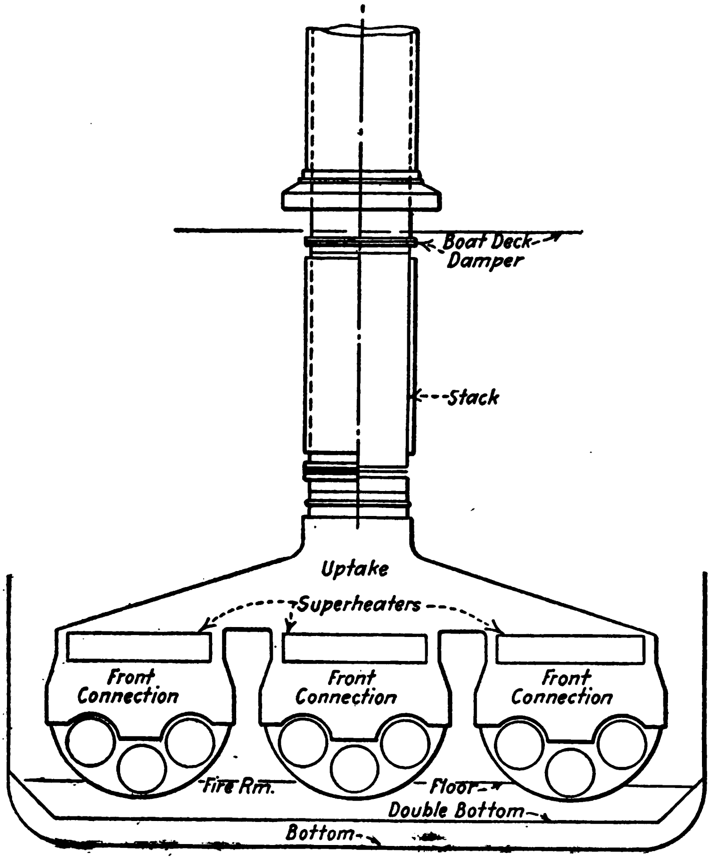


Fig. 28. Uptake System Showing Connections to Stack 8800 Ton Cargo Ship

dependent uptake. These join together near the funnel, thus allowing the gases to get a distance from the boiler before mixing with gases from the other boilers.

(*c*) ***Front connection.*** A system of galvanized plating is

attached to the boiler and forms the front connection. It extends far enough away from the tube ends to allow withdrawal of any tube. There are upward swinging doors in

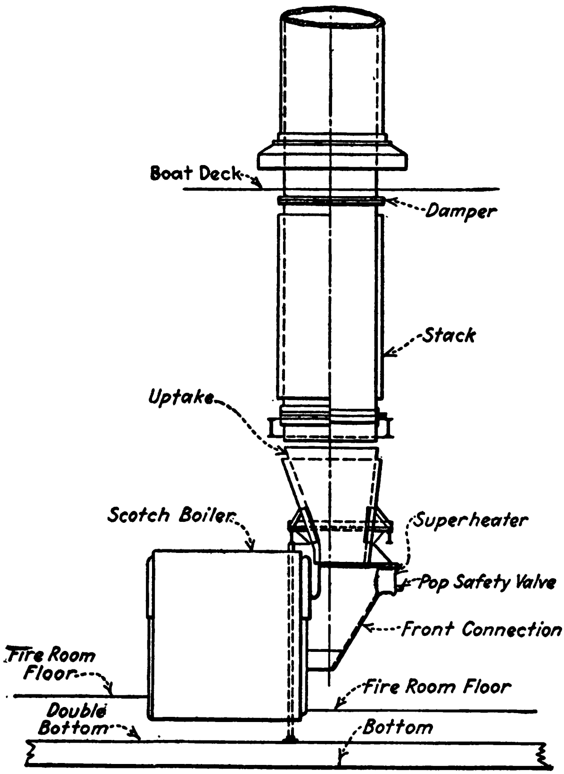


FIG. 29. Boiler Connection to Stack

the front of the casing which are opened for the purpose of sweeping the tubes when under steam. A second casing surrounds the smoke box and uptake. This is thinner than

the inside casing and is held at several inches from it. There is an air space between the two casings through which the air from the fire room can enter. The air passes out either at the highest point in the fire room or else to some elevation above the upper deck, around the funnel. There is a double casing on the smoke box doors also, the heated air being allowed to escape just above the doors. A wall of galvanized plating is often fitted between boilers and parallel to the front of them at several feet back from the front end. Its purpose is to prevent dust and ashes being carried into the space behind. It also helps to keep up the air pressure, near the furnace fronts, in forced draft systems. There are doors in the casing for access to the parts behind. It is possible, and at times desirable, to use the space thus formed on each side of the boiler, to warm the air being supplied the fire near the rear end of the grate.

(*d*) *Dampers.* A swinging damper is usually placed in each uptake for controlling the draft. Sometimes these dampers are omitted, and a single damper in the funnel serves this purpose. Dampers are not ordinarily provided on oil burning boilers. Dampers must be made heavy enough to stand the intense heat without warping. They are so constructed that the amount of opening can be regulated at will.

13. Clothing

(*a*) *Purpose.* Clothing reduces the amount of heat lost by radiation and incidentally reduces the temperature of the fire room.

(*b*) *Material.* It consists of an incombustible, non-heat-

conducting material such as magnesia, asbestos or silicate cotton.

(*c*) *How put on.* The clothing is generally put around the upper part of the shell and over the back head, and is carried down to a level just clear of the supports. It is usual to clothe only the upper part of the front head. The clothing is about $1\frac{1}{2}''$ thick. The clothing is put on after the boiler has been installed and tested.

14. Lagging

(*a*) *Purpose.* This is used to protect and keep the clothing in place.

(*b*) *Material.* The lagging consists of thin galvanized wrought iron plates and angles. Galvanized iron bands are used to hold the clothing against the shell.

(*c*) *Method of fastening.* The plates are flanged outwardly and are bolted together and held away from the boiler by distance pieces. Bolts, which are tapped a short distance into the shell, hold these in place. In cases where the bottom of the boiler is fitted with clothing, this and the lagging for it, is made in sections, which can be removed when necessary.

QUESTIONS

1. Describe how the shell of a Scotch boiler is made.
2. What type of joint is used for the circumferential seam? What type for the longitudinal seam?
3. (*a*) What is the usual number of plates in the back head of a Scotch boiler?
   (*b*) Is the flange turned on the head or on the shell?
   (*c*) How are the flanges made?

4. (*a*) In a large boiler, how many parts is the front head divided into?
   (*b*) Name them. Give the important openings in each.
   (*c*) In a small boiler, how many parts may there be to the front head?
5. What is the advantage of making the tube sheet a separate part?
6. What type of joint secures the front sheets together?
7. Is it usual for the flange to be turned in or put on the front head?
8. Describe the construction of the furnace sheet, method of making furnace holes, and manner of flanging.
9. Why is the tube sheet made thinner than the other sheets?
10. What are braces or stays used for?
11. Define through stays and tell where they are used.
12. What are stay bolts? Screw stays?
13. How are sub-stays fastened to the combustion chamber?
14. What are gusset stays?
15. Why do stays sometimes have forked ends?
16. How many kinds of tubes are used in Scotch boilers? Are any curved tubes used?
17. How are common or ordinary tubes fastened in the tube sheets?
18. How are stay tubes fastened? What is the purpose of the stay tubes?
19. What are ferrules?
20. What are retarders?
21. What is the usual type of furnace now employed?
22. How are furnaces made?
23. Of what materials are grate bars made?
24. What limits the length of the grate?
25. How are manholes formed? What is the stiffening ring?
26. What does the furnace front consist of?
27. Explain the difference between the hinged door and the balanced door.

28. What is the purpose of the dead plate?
29. How is the combustion chamber constructed?
30. Explain the various ways in which the combustion chamber is braced.
31. Where are the uptakes located?
32. What is the smoke-box?
33. Of what does the clothing consist and what is its purpose?
34. What is lagging used for and what is it made of?

SKETCHES

1. Show a side view of a Scotch boiler.
2. Sketch a section through shell showing butt joints.
3. Sketch rear head of Scotch boiler.
4. Sketch front head of three furnace Scotch boiler.
5. Sketch a front tube sheet.
6. Show a through stay bolt.
7. Sketch a through stay.
8. Sketch a sub-stay.
9. Sketch a common tube.
10. Sketch a stay tube.
11. Show by means of a sketch the furnace connections to head and to combustion chamber.
12. Sketch a cast iron grate bar.
13. Sketch a dead plate.
14. Sketch furnace front, showing an open type door.
15. Make a cross-section of a furnace door, showing liner attached.
16. Sketch a front view of combustion chambers for a two furnace boiler, showing method of support.
17. Show a side view of a combustion chamber.
18. Make a cross-section of a manhole, showing cover in place.
19. Show by means of a sketch, how the uptake system connects to the stack.

LESSON 3 — WATER TUBE BOILERS

1. Difference between Water Tube Boilers and Fire Tube Boilers

(*a*) *Weight.* The weight per horsepower is much less in water tube boilers than in fire tube boilers. The difference in weight is of course due to the construction. In the water tube boiler the drums seldom exceed 48″ in diameter, whereas the diameter of the Scotch boiler may be as much as 17 feet. The following figures serve to give a general idea of how weights vary for the same boiler horsepower:

Scotch Boiler, double ended	2000 H. P.	70 tons
Water Tube	2000 H. P.	15 to 20 tons

(*b*) *Difference of construction.* Due to the method of construction, the water tube boiler may be termed a flexible boiler. All water tube boilers have special provisions made for expansion and contraction, such as curved tubes in express boilers, sections free to expand or contract, as in the B. & W., etc. In all express boilers, high horsepower is obtained at a sacrifice of fuel, as compared to the fire tube boiler. Fire tube boilers do not lend themselves to quick raising or lowering of steam, whereas it is possible to raise or lower steam with an express boiler in 15 or 20 minutes.

(*c*) *Table showing where each type is most suitable.* This table shows which type of boiler excels for various conditions and purposes:

Where feed cannot be rigidly restricted to fresh water..........	Fire tube
For least attention to regularity of feed......................	Fire tube
For least expert handling and attention......................	Fire tube
For extreme lightness..	Water tube
For rapidity of raising steam................................	Water tube
For cheapness..	Fire tube
For highest speed with least weight..........................	Water tube
For least danger from disastrous explosion....................	Water tube
For greatest portability.......................................	Water tube
For easiest cleaning and inspection..........................	Fire tube
For least sensitiveness to variations of use....................	Fire tube
For highest efficiency per sq. ft. of heating surface.............	Fire tube
For ability to stand forcing...................................	Water tube
For strength..	Water tube
For least number of parts.....................................	Fire tube
For simplicity of construction................................	Fire tube
For least labor in operation and cleaning.....................	Fire tube
For least radiation loss from furnace.........................	Fire tube.

2. Classification of Water Tube Boilers

(*a*) *As to circulation:*

(1) *Limited circulation.* In this type there are two currents in opposite directions in the same containers, but in spite of this there is a sluggish circulation of the water. The flow is supposed to be downwards from the steam drum to the lowest tube element and then gradually upwards through the tubes. The following boilers are examples of limited circulation: Belleville; Thornycroft (old type); Almy; and Roberts.

(2) *Free circulation.* Special provision is made in this type for the cold water to come down and the hot water to come up. The velocity of flow is moderate. The water flows from the drum down into a header and thence through a large number of tubes having a slight inclination

upwards, and finally returning through another header to the drum. Examples of this type are: B. & W.; Caldwell and Root. Other examples of this type of circulation (although method of obtaining it calls for a double concentric tube and only requires a front header) are; Dürr and Niclausse.

(3) *Accelerated circulation.* In these boilers, special provision is made to obtain extra fast circulation. The tubes are of small diameter, and have a nearly vertical slope. They may be straight or curved. The circulation may be through large tubes called downcomers to lower drums called mud-drums and then up through the nearly vertical tubes; or in many cases the downcomers are dispensed with and the outer row of tubes used for this purpose. In all these boilers there is a small volume of water in comparison with the relatively large heating surface. Examples of the accelerated circulation, called *express boilers*, are the Yarrow, White-Forster, Normand, Thornycroft, Seabury, Mosher, Du Temple and Reed.

(4) *Forced circulation.* As this type of boiler is no longer used in marine work, it will be disregarded in this book.

(*b*) *As to size of tubes:*

(1) *Large tube.* Boilers having tubes 2″ and over in diameter are classified as large tube boilers.

(2) *Small tube.* Boilers having tubes less than 2″ in diameter are called small tube boilers (*express boilers*).

(*c*) *As to where tube enters steam drum:*

(1) *Drowned tubes.* If the ends of the tubes delivering steam to the drum are below the level of the water in the

steam drum the tubes are called drowned or wet tubes. All express boilers are of this type.

(2) *Semi-drowned tubes.* Tubes deliver steam either above or below the water level in the steam drum as this level varies. Many water-tube boilers are of this type.

(3) *Above water or dry tubes.* Steam is delivered to the steam drum above the water level. This method is found in the old types of water tube boilers only.

3. Advantages of Water Tube Boilers

(*a*) *Weight per horsepower.* For the same horsepower, the water tube boiler may be constructed to have approximately one-fifth the weight.

(*b*) *Overloads possible.* An 800 H.P. water tube boiler may be operated to give 1600 H.P. or more. The only limit to the overload is the amount of heat in the furnace and the amount of water available in boiler for forming steam. If the tubes are kept full of water all the heat possible to be obtained can be put on the other side of the tube. This overloading is not possible in the Scotch boiler as its rigid construction forbids the possibility of such forcing. An overload of 100 to 150 per cent is not uncommon in water tube boilers.

(*c*) *Inherent strength.* The material in the water tube boiler is much thicker than is absolutely necessary to hold the pressures carried. It is made thick for ease in working. For this reason it will stand very much higher pressures than working pressures. In the better class of water tube boilers there are no screw fittings. All the tubes are expanded.

4. Disadvantages

(*a*) *Inspection.* One disadvantage of the water tube boiler is that thorough inspection of the water side is impossible.

(*b*) *Cleaning.* Another great disadvantage to water tube

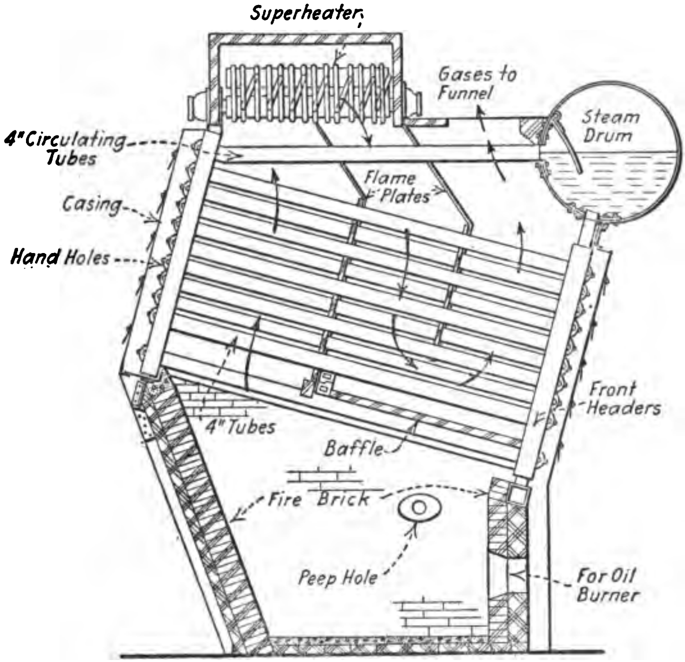


FIG. 30. Cross-section of B. & W. Boiler-oil Burner

boilers of the B. & W. type is the relatively great expense, both in time and labor, of cleaning them.

5. Babcock & Wilcox Boiler (Fig. 30)

(*a*) *Form.* The B. & W. boiler is rectangular in form. It is made up of a steam drum, tubes, headers, nipples, cross-

boxes, side boxes and water legs connected together to provide for a definite circulation of the water. The construction is explained in detail in the next lesson.

(*b*) *Water circulation.* The water passes from the drum to the front headers and then to the back headers through the tubes, each header supplying its own tubes; it then passes up to the rear cross-box. On leaving the rear cross-box steam is mixed with the water and the steam and water pass through the 4″ circulating tubes to the drum. Some water will pass down from the front headers to the front uprights. This passes back through the side boxes and side and center tubes to the back uprights and then through back headers to the drum.

(*c*) *Path of steam.* Steam passes from the drum through the dry pipe, then passes a stop valve fitted on the drum and is conducted by piping to one end of the superheater. In some boilers the steam enters at one end of the bottom superheater cross-box and, after being deflected through the tubes by a series of diaphragms, leaves the superheater at the other end of the lower cross-box; in other boilers the steam enters at one end of the upper cross-box and after being deflected through the tubes, leaves at the other end of the upper cross-box.

(*d*) *Path of gases.* The gases from the fresh fuel are forced to the back of the boiler by the roof of light fire tile which extends part way over the furnace. Thus they pass over an incandescent bed of coal and under the hot tile roof. The gases have space and time to mix thoroughly and burn before entering the bank of tubes forming the heating surface, due

to the increase of height of the furnace near the bridge wall Flame plates and baffles then force the gases to follow a circuitous route so that they cross the heating surface three times before passing out through the uptake.

(*e*) *Method of support*. The boiler frames and casings are fastened to angle irons and supporting irons and these in turn are fastened to special framing built into the ship. The front water legs or uprights of the boiler support the front headers. The rear water legs support the rear headers by means of an I-beam and are themselves supported by dry legs.

(*f*) *Provision for expansion*. The horizontal I-beam at the rear is supported by an angle bracket bolted to the water leg and this supports the rear headers which slide on it. Thus they are free to expand or contract. The sectional nature of the boiler also allows all pressure parts to expand or contract, as necessary.

(*g*) *General description of B. & W. oil burner*. The tubes are made of cold drawn seamless steel. They are all 2″ tubes, except the top circulating tubes, the bottom row of tubes which hold the roof baffle, and the side tubes, all of which are 4″ tubes. The boiler is fitted with an Ashton twin safety valve. The main boiler stop valve is a globe valve. Immediately behind it is a check valve. There is no provision made for a water column, but there are two gauge glasses, flange connected, and fitted on the front of the steam drum. B. & W. balanced, or fulcrum try-cocks are fitted. These are operated by lifting up the bulb. The main and auxiliary feed stop and check valves are located

on the steam drum and are controlled by extended spindles operating through gears.

QUESTIONS

1. What are the main points of difference between water tube boilers and fire tube boilers?
2. For what uses are water tube boilers especially adapted?
3. In what cases does the fire tube boiler excel?
4. Classify water tube boilers as to circulation.
5. Classify water tube boilers as to size of tubes.
6. Classify water tube boilers as to where tubes enter steam drum.
7. Name three important advantages of the water tube boiler.
8. What are two important disadvantages inherent in water tube boilers?
9. Give a general description of the Babcock & Wilcox boiler, with special reference to form, water circulation, path of gases, method of support, and provisions made for expansion.

LESSON 4 — WATER TUBE BOILERS — CONSTRUCTION OF B. & W. BOILER

1. Drum

(*a*) *Sections of shell* (Fig. 31). The steam drum is formed from two sheets of boiler steel, one of which takes up three-quarters of the circumference and the other the remaining one-quarter. The plates are $\frac{1}{2}''$ thick. They are formed cold in a hydraulic forming machine, one section being formed

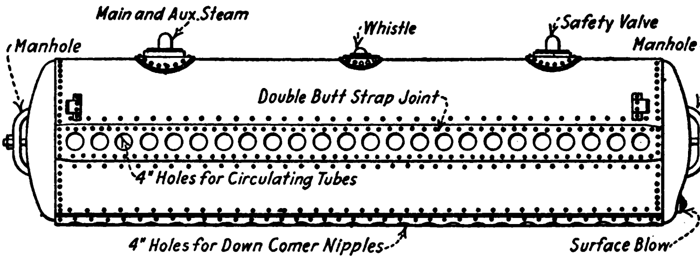


FIG. 31. Rear View of Steam Drum B. & W. Boiler

at a time. Each section is then tested with a gauge for the proper curvature.

(*b*) *Riveting*. Before forming, while the sheets are still flat, the rivet and punch holes are all marked out with the aid of a templet. All rivet holes are next punched both for the heads and for the butt strap. These holes are punched one-quarter inch smaller than the size of rivets as driven. At the edges of the plates, the semi-circular holes are punched for

the downtake nipples and the circulating tubes. Thus they come at the butt joint, so that the space between them is strengthened by it. Pilot holes for the butt straps are drilled. The straps are curved to the proper radius in a hydraulic press and after the sheets are formed the inner and outer straps are bolted in place by means of the pilot bolts. All rivet holes are next reamed to full size. The whole drum is then riveted together and the 4″ holes for the downtake nipples and the circulating tubes are reamed with a radial rose reamer. The holes in the drum are punched larger than the drilled holes in the butt straps so that a shoulder can be expanded on the downcomer nipples and the circulating tubes. The 4″ holes in the butt straps are drilled before assembling, the two straps being bolted together. After the drum is assembled, the straps and plates are held in place by means of a few pilot bolts and rivets and the bulk of riveting is done with a hydraulic bull riveter.

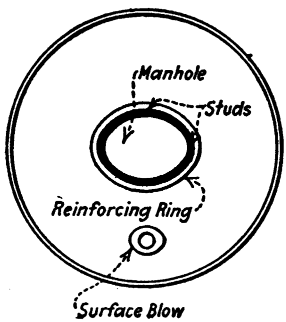


FIG. 32. Drum Head Showing Manhole Opening — Inside View of Drum Head

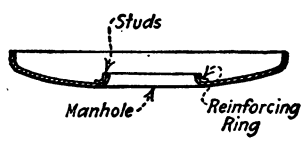


FIG. 33. Section Through Drum Head

(*c*) *Forming drum heads* (Figs. 32 and 33). The drum heads are formed in a hydraulic forming press. The reinforcing ring is laid on the die and the circular sheet of steel is laid on top of that, both having been heated in the same furnace to the same temperature. In

the first operation, the manhole is punched through, and in the second the reinforcing ring and outside of the drum head are flanged over it. The material of the drum heads is forged steel. Flat raised seats for water glass and feed connections are formed in the forging.

(*d*) *Manholes.* Manhole openings are provided in the heads and the edges are machined for gaskets in a vertical boring mill, the burrs being removed by a portable emery wheel.

(*e*) *Manhole covers.* The manhole plates are of forged steel and are turned to fit the manhole opening. These plates are held in position by forged steel guards and bolts.

(*f*) The heads and drum are riveted together by means of a hydraulic bull riveter. The die of this riveter is so made that it can be inserted through the manhole of the head.

2. Steam Drum Fittings (Internal)

(*a*) The *scum pan* is fastened to the swash plates and leads to the surface blow. The scum pan aids in the collection of scum or foreign matter from the surface of the water in the drum.

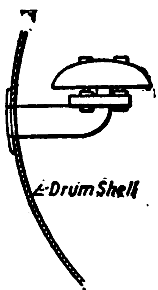


FIG. 34. Umbrella Feed

(*b*) The *fusible plug* is screwed in from the inside. It is located between the downcomer nipples and the circulating tubes, near the center of the drum. The plug is made of composition metal and is filled with Banca tin.

(*c*) The *zinc plates* are fastened between the two swash plates and are held in a perforated zinc basket.

(*d*) The *internal feed water lines* are fitted with "umbrella"

deflectors used for the purpose of deflecting the feed water to as many of the downcomer nipples as possible (Fig. 34).

(*e*) A *dry pipe* (Fig. 35) is fitted in the top part of the drum. It is in two parts, flanged in the center and fitting into elbows

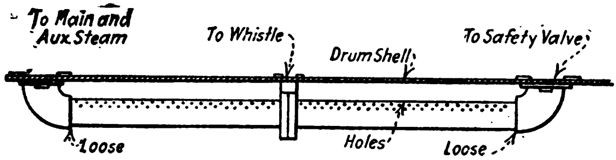


FIG. 35. Dry Pipe

at each end. Its function in this boiler is that of a collecting pipe. The aggregate area of the holes in the top of the dry pipe is greatly in excess of the area of the steam outlet from the drum so that in this case it does not restrict the

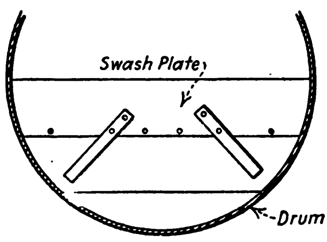


FIG. 36. Swash Plate

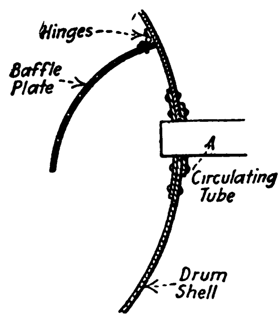


FIG. 37. Baffle Plate

flow of steam from the boiler. It extends nearly the whole length of the drum and is supposed to draw steam evenly from the whole length of the steam space.

(*f*) Two *swash plates* (Fig. 36) are placed so that they divide the drum into three equal lengths. They are to

prevent rushing of the water in the drum from one end to the other when the ship is rolling excessively. They will relieve, to a small extent, the dipping of the dry pipe into the water.

(*g*) *Baffle plates* are located directly over the circulating tubes (Fig. 37), and are secured to the drum by hinges. The hinges are secured on angle irons, riveted to the drum. The hinges are kept from moving by means of dogs securing the baffle plates to the swash plates. They are used to

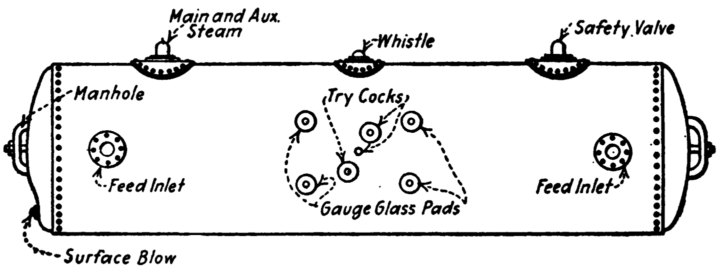


FIG. 38. Front View of Steam Drum Showing External Fittings B. & W. Boiler

prevent water from the circulating tubes from rising with the steam to the dry pipe.

(*h*) *Portland cement* is placed around the edges of the fittings on the inside of the drum by means of a hand trowel. It is used for the purpose of closing off air pockets.

3. Steam Drum Fittings (External) (Figs. 38 and 39)

(*a*) The opening for the *safety valves* is on top of the drum, about three feet from the end. This is also the end of the dry

pipe. The hole is 4″ in diameter. The valves are placed on nozzles which fit on the drum. These are made of forged steel, are faced and are fitted with taper thread stud bolts.

(*b*) Provision is made for three *try-cocks* on the front center of the drum. The top and bottom ones are fitted with pads while none is used on the center. The pads are so fitted that they extend out from the drum perpendicular to a plumb line through the center try-cock and not radially from the drum. The try-cocks are made of brass. Each

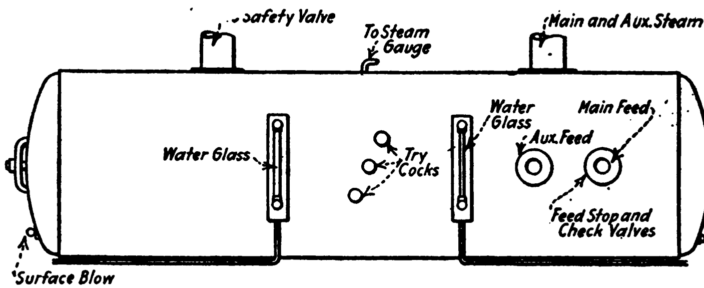


FIG. 39. Steam Drum and Fittings B. & W. Boiler

consists of a valve kept on its seat by means of a threaded spindle. When the threaded spindle relieves the pressure, the steam acting against the valve seat pushes it back and opens the valve allowing water or steam to flow past.

(*c*) Provisions are made for two 12″ *water glasses*, one on each side of the try-cocks.

(*d*) The opening for the *main and auxiliary steam fittings* is at the other end of the dry pipe from the safety valve opening.

(*e*) The *surface blow* is attached to the scum pan and is connected to the drum head below the manhole.

(*f*) There are openings in the front center of the drum, about 1½ feet from each end for the *main* and *auxiliary feeds*, respectively.

4. Headers (Fig. 40)

The headers are formed from a cold drawn, seamless, steel tube, 6″ diameter, of ½″ thickness. This is heated up to a white heat in a producer gas furnace. A square expanding mandrel is inserted while the tube is still in the furnace. On the way out of the furnace, the tube passes between two rollers, which give it a squared cross-section.

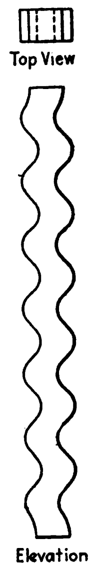


FIG. 40. Detail of Header before Drilling

(*a*) *Staggering.* At the same heating, a flexible sectional mandrel and forming block are inserted and the header is staggered by means of a hydraulic stagger press of 15,000 tons capacity, equipped with an external staggering die. The purpose of staggering is to prevent a direct flow of the hot gases between the tubes expanded in the headers. The staggering forces the hot gases to travel in and out among the tubes, thus enabling them to give up more of their heat.

(*b*) *Closing ends.* The headers are burnt to length by an oxy-acetylene flame. They are then taken to the forge and the ends closed in the following manner. The end is heated to a red heat, then taken out of the fire and expanded slightly. A square block of steel 1″ thick is then inserted in the end and the sides are hammered down to hold the block in place. It is then brought to a

welding heat for each side and each side is welded separately. Thus in all, there are five heats required for the operation of closing each end.

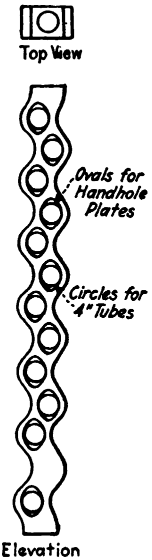


FIG. 41. Header Showing Oval Handhole Openings

(*c*) *Testing headers.* A ½″ diameter hole is drilled in the end of each front header and in the side of a rear header, where a handhole will be placed later. This is then connected to a hydraulic testing line, and the header must stand a pressure of 450 pounds per square inch.

(*d*) *Method of drilling headers for tubes and handhole plates.* The headers having 4″ tube holes have the oval handhole plates (Fig. 41). These are staggered, and thus there are two lines of holes. A gang drill is used which drills one line of these holes at a time. It drills the holes for the tubes on one side and the holes for the handholes on the other side, in one operation. The handholes are next made oval in shape by means of a profiling machine, the cutters of which operate in gangs like the cutters of the drill. The bed on which the header rests is given an elliptical motion and in this manner the cutters profile an elliptical or oval hole.

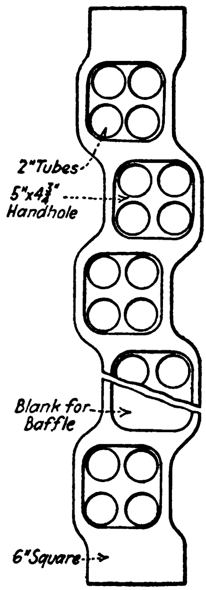


FIG. 42. Header Showing Square Handhole Openings

In the headers for the 2″ tubes (Fig. 42), the handholes are made square and there is a handhole opposite every group of four 2″ tube holes. The tube holes are drilled by a gang drill as in the case of the 4″ holes and then the square handhole is profiled by setting the header on a bed having a square motion. Instead of using a milling cutter, as in the case of the oval holes, twist drills are used in this machine.

(e) *Facing inside of handholes for gasket of handhole plate.* The oval handholes are faced on the inside for the gasket and handhole plates by means of a steeple cutter, which not only faces the inside, but also performs the profiling in one operation. The facing is a separate operation in the case of the square handholes.

(f) *Handhole plates.* The handholes are closed by inside fitting forged plates, shouldered to center in the opening, their flanged seats milled to a true plane. These plates are held in position by studs and forged steel binders and nuts. The joints between plates and headers are made with a thin gasket.

(g) The various headers may be classified as follows:

(1) *Front end headers.* These have 4″ holes drilled in the top for the downtake nipples and they connect on the bottom by means of 4″ upright nipples to the right and left front uprights respectively. They are also connected to the back headers by means of the 2″ tubes, the bottom row being 4″ tubes. In this connection it should be noted that in some boilers all the tubes are 4″ tubes.

(2) *Front intermediate headers.* These have the 4″ holes drilled in the top for the downtake nipples and on the

bottom they connect to the lower front cross-boxes by means of the cross-box header nipples. They are connected to the back headers in the same manner as the front end headers.

(3) *Front center header.* The center header has a hole in the top for the downtake nipple and in the bottom for the upright nipple connecting to the front center upright. It is connected to the back header in the same manner as the other front headers.

(4) *Back end (right and left corner) headers.* Connect to the back uprights by means of upright nipples at the bottom.

(5) *Back intermediate headers.* These rest upon an I-beam which supports them but allows freedom for contraction or expansion.

(6) *Back center header.* This is connected to the back center upright at the bottom, by means of a nipple.

All the back headers are connected to the rear cross-box by cross-box nipples at the tops.

The headers are inclined at an angle of 15 degrees from the vertical.

5. Tubes

In some boilers all the tubes are 4″ tubes. In others all the tubes are 2″ with the exception of the bottom tubes, side tubes, and circulating tubes, which are 4″. In this case the 2″ tubes connect the front and rear headers, as explained above; the circulating tubes connect the rear cross-box with the steam drum; the bottom tubes connect the front and rear headers; and the side tubes are connected between the front uprights and the back uprights.

The tubes are made of hot finished seamless open hearth steel. They are of No. 10 B.W.G. where the boilers are built for working pressures up to 210 pounds and are of No. 9 B.W.G. where the working pressures are to be up to 260 pounds. The tubes are expanded into the headers and as these are made serpentine in form, as explained above, the tubes are disposed in a staggered position when assembled complete.

All tubes are inclined at an angle of 15 degrees with the horizontal, with the exception of the circulating tubes, which are horizontal.

6. Downtake Nipples

Each one of the front headers is connected with the steam drum by means of a 4″ downtake nipple. The number of front headers may vary from 12 to 42. Twenty-four is the usual number. Thus in the latter case, there would be 24 downtake nipples. In the older type of boilers, the downtake nipples served, not only to connect the steam drum and the headers, but also to help support the steam drum. *Supporting sleeves* are now used on the outside of each downtake nipple and these serve to act as supports, taking the weight off the nipples. The downtake nipples (sometimes referred to as downcomer nipples) are expanded into the drum at the top and into the header at the bottom.

7. Uprights or Water Legs (Fig. 43)

(*a*) *End uprights.* The front uprights at the right and left of the boiler are connected to the right and left lower front cross-boxes, respectively, by means of cross-box nipples.

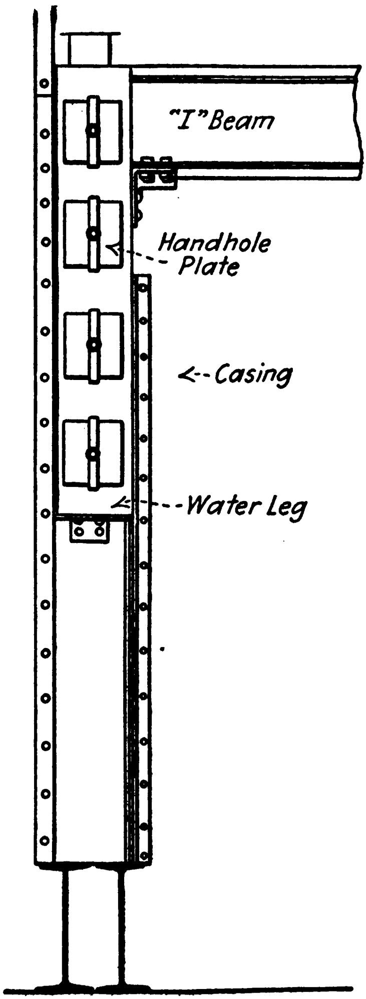


FIG. 43. Sketch of Bottom Part of Casing Showing Back Water Leg

They are also connected at the top to the right and left end front headers by the upright nipples. These uprights constitute the weakest part of the boiler, since they have four openings around the top part, including the handhole opening and the opening for the side tube.

The back uprights at the right and left of the boiler are connected at the top to the right and left end back headers, respectively. The back uprights are connected to the front uprights by side tubes and side boxes.

(*b*) *Center uprights.* The front center upright is connected at the top to the front center header. It is connected to the lower left cross-box by an end cross-box nipple. It is connected to the back center upright by a 4″ center tube and center boxes.

The back center upright is connected at the top, by means of an upright nipple, to the back center header. It is connected to the front center upright as explained above.

Bottom blow connections are fitted at the side of the bottom of each front corner upright. In each upright there is one handhole for each 4″ side or center tube and one for each side box. These handholes are closed by handhole plates

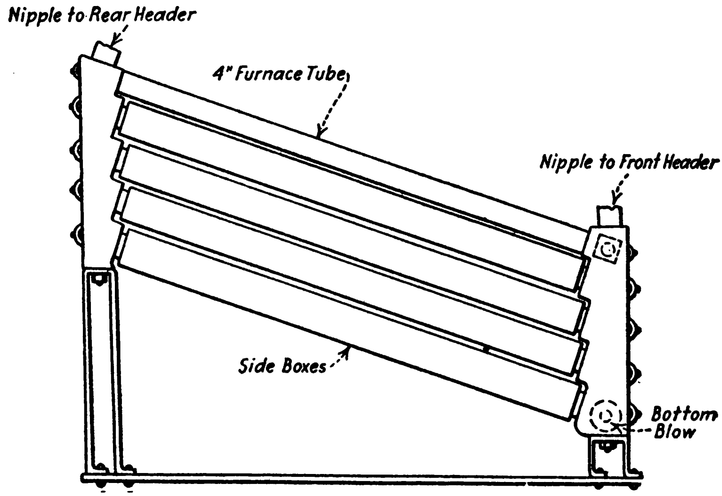


FIG. 44. Sketch of Side Boxes

which make a joint on the upright with a thin gasket. The plates are secured in place and made tight with dogs.

8. Side Boxes (Fig. 44)

(*a*) ***Form and construction.*** The side boxes are formed in much the same manner as the headers except that they are not serpentine in form. They are formed from cold drawn

seamless steel tubes, $\frac{1}{2}''$ thick and $6''$ in diameter. The tube is heated up to a white heat in a producer gas furnace. A square expanding mandrel is then inserted while the tube is still in the furnace. On the way out of the furnace, the tube passes between two rollers which give it a square cross-section. The boxes are burnt to length by means of an oxy-acetylene flame. They are then taken to the forge and the ends are closed in the following manner. The end is heated to a red heat and then taken out of the fire and expanded slightly. A square block of steel $1''$ thick is inserted in the end and the sides are hammered down to hold the block in place. It is then brought to a welding heat for each side, and each side is welded separately. Thus there are five heats in all required for the operation of welding the ends. Another method of forming the side boxes is to bend a flat sheet of steel to a square cross-section and lap weld it.

(*b*) *When used.* Side boxes are used only in coal burners. They tend to prevent the clinging of clinkers at the sides, as the clinkers will not stick to the comparatively cool metal surfaces. In oil burners, this space is filled with fire brick which gives a very high temperature.

(*c*) *Connections to uprights.* The side boxes are connected to the front and back uprights by side box nipples as mentioned above.

(*d*) *Slope.* The side boxes are inclined at an angle of 15 degrees from the horizontal.

(*e*) *Four inch tubes.* There is a four inch tube on each side of the boiler, above the side boxes, and connecting the front and back uprights.

9. Cross-Boxes (Fig. 45)

(*a*) ***Front cross-boxes — how connected.*** The right and left lower front cross-boxes (sometimes called mud-drums) connect the front intermediate headers to the front uprights. In some cases there is only one cross-box in the front instead of two. In the oil burning boiler, there are no water legs or uprights; and hence the blow-off connection is located at

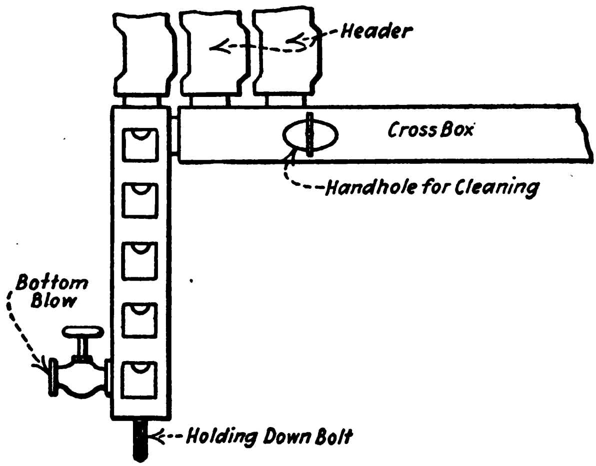


FIG. 45. Sketch of Cross Box

the end of the mud-drum, instead of at the bottom of the front water legs, as in the coal burner. In the oil burner, the mud-drum is connected by means of tubes to the rear headers.

(*b*) *Rear cross-boxes — how connected.* The rear cross-box connects the rear headers with the steam drum by means of the circulating tubes. In some boilers, this cross-box is

omitted, the circulating tubes connecting directly from the steam drum to the rear headers.

(*c*) *How formed.* The cross-boxes are formed in the same manner as described above for the side boxes. The holes for the nipples, which make the connections between the headers and the uprights, are drilled in a gang drill.

10. Furnace

(*a*) *Coal burner:*

(1) *Material.* The roof of the furnace is formed by fire tile roof blocks, which are laid over the 4″ bottom tubes, extending from the front of the furnace to about five-eighths the length of the tubes. Baffle blocks for the 2″ tubes are situated at the end of the roof block. The side-boxes form the sides of the furnace. The back of the furnace is formed by the bridge wall which is built up of fire brick and slopes gradually upward from the ends of the grates to the bottom of the rear headers. The bricks are laid on a layer of asbestos, the entire wall being supported by an angle iron framework.

(2) *Dead plate.* The dead plate is just below the furnace door. It is of cast iron and is carried on an angle iron support riveted to the door frame. In this case the ends of the grate bars do not rest on the dead plate, but are supported by a wrought iron bearer bar. A similar bar is placed at the back, double bearer bars being used at the center. The grate bars are standard cast iron bars and extend practically the entire length of the furnace.

(3) *Division blocks.* Fire brick division blocks are placed between the side boxes and the side tubes and also between the side tubes and the bottom tubes. They are also placed between the bottom tubes and the center tube. Cast iron division blocks are fitted between the top center box and the center tube.

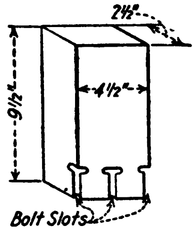


FIG. 46. Furnace Tile (This type of tile laid so as to get 9½" protection — Secured by means of bolt slots at bottom as shown.)

(*b*) *Oil burner.* The furnace is lined with fire bricks (Fig. 46). Those on the furnace floor are laid down without being cemented together. On the sides and back, the bricks are cemented together, and run up to the tubes, as shown in Fig. 47. In the front, the courses of brick run up to the roof baffle, openings being provided for the burners. The roof baffle is laid on the bottom row of tubes and extends about five-eighths of the way back. The first three rows from the front of the furnace are composed of bricks which completely surround the tubes. These protect the tubes from the intense heat of the burners directly underneath them. The remaining rows of fire brick are simply laid on the top of the tubes and serve as the baffle to direct the gases to the rear of the furnace.

11. Furnace Fronts and Doors

(*a*) *Door frames.* Furnace fronts are riveted at the top and bottom to angle irons and at the sides to I-beams. These are usually called the furnace door frames, since they carry the furnace doors.

(*b*) *Jambs*. Furnace door jambs and door lintels are provided between doors and also at the right and left between the doors and the right and left uprights, respectively.

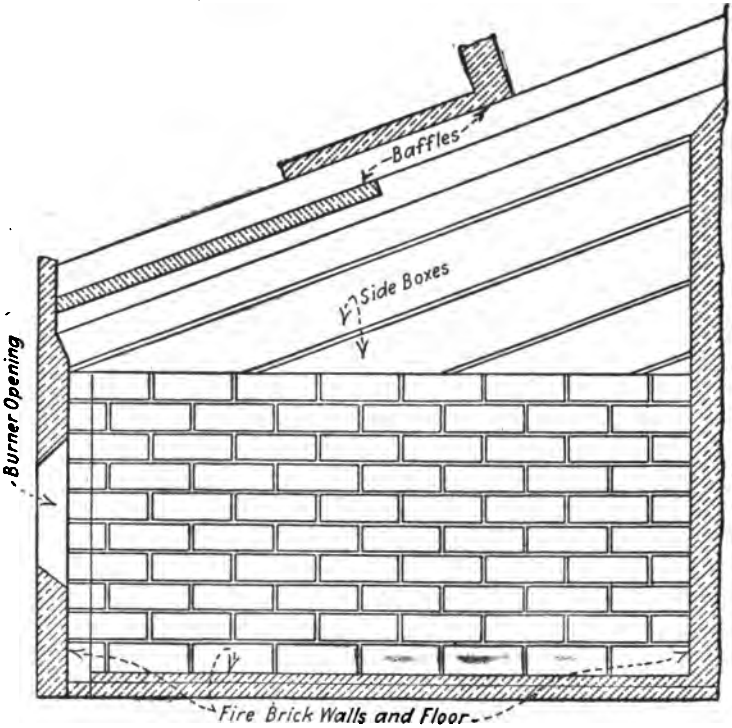


FIG. 47. Interior View of Furnace B. & W. Oil Burner

(*c*) *Dead plates*. The dead plates are cast iron fittings. They serve the same purpose as in the fire tube boiler. They are just below the furnace door and are carried on supports riveted to the door frame.

(*d*) *Outswinging door*. This is the older type of door carried

on hinges at the side which are attached to the door frame. The backs of these doors are lined by ***furnace door liners*** of cast iron. The more modern type of ***balanced door***, described in connection with Scotch boilers, is sometimes supplied. The doors are usually provided with a small slicing door for the purpose of inserting a s ice bar, without opening the large door. The balanced doors are also referred to as ***in-swinging doors***.

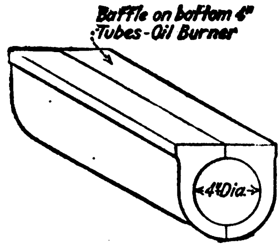


FIG. 48. **Baffle Tile**
(The tiling is formed in a mold and baked)

12. Roof Baffle

Fire tile roof blocks (Fig. 48) are laid over the 4″ bottom tubes, as described in paragraph 10, and these form the roof baffle.

13. Flame and Baffle Plates

(*a*) ***Front flame plate.*** A built-up steel ***baffle plate*** extends downwards at an angle from the top of the boiler. It reaches the tubes at a distance from their front ends of a little over one-quarter of their length. ***Flame plates*** then form the bottom of the baffle plate. They are placed perpendicular to the tubes, and reach from the top of the tubes to about 60 per cent of their depth from the top. The flame plates are of steel sections. They are slid in between rows of tubes and then turned to a vertical position. They then fit around the tubes, as they have semi-circular holes drilled in them. At each end of the section there is a hole drilled and a bolt is passed through this hole, thus securing the plate to the angle iron along the side.

(*b*) *Rear plates.* Flame plates extend from the baffle blocks at the rear end of the roof block covering (at right angles to the direction of the tubes) to the upper row of tubes, and they are then fastened to a baffle plate which inclines upward to the superheater baffle blocks. Since the flame plates are in section they are comparatively easy to renew. The flame plates are provided with fire brick protectors, which are inserted between the tubes before the tube and header sections are placed on the foundations, being held in place temporarily with strings.

(*c*) *Purpose.* The purpose of the flame and baffle plates is to cause the gases of combustion to cross the tubes three times. The circulation of the gases is as follows: They pass to the back of the furnace between the tile roof block covering and the fuel bed, then up between the tubes at the back of the boiler to the superheater tubes. After passing around these tubes they are deflected downward between the front and back flame plates, thus passing across the tubes a second time. They then pass up across the generating tubes a third time, passing between the front flame plates and the front headers, and finally they pass out through the uptakes. The three passages between the back and the front of the boiler, for the travel of the gases across the tubes, are called first, second and third pass, respectively.

14. Clothing and Casing

(*a*) *Filling between headers.* Asbestos rope is used to fill the spaces between the headers.

(*b*) *Side tube tile.* The spaces between the side tubes are

filled with light fire tiles made of highly refractory fire clay.

(*c*) *Mill board.* Against the side tubes are placed asbestos mill board and magnesia block covering.

(*d*) *Casing plates.* On the outside, firmly holding the non-conducting materials in position, are the casing plates, which are clamped to the structural framing by butt straps.

15. Cleaning Doors

(*a*) *Front and rear connections.* Hinged to the framing at the front and rear of the boiler are large doors, giving access to the handhole plates covering the tube ends. These are usually (though not always) hinged at the top, so that they can be swung out and upwards.

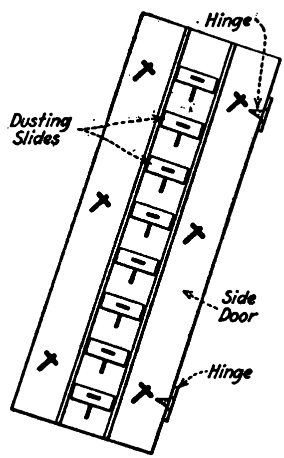


FIG. 49. Sketch of Side Door Showing Dusting Slides

(*b*) *Side doors* (Fig. 49). Hinged to the sides of the boiler are several doors which, when opened, allow for the inspection and cleaning of the tubes. They are sometimes called cleaning panels.

(*c*) *Dusting doors.* Small dusting doors are enpaneled in the side doors and a steam lance may be inserted through them for the purpose of blowing the soot from the exterior of the tubes. Each opening is covered by a shutter, sliding vertically, which can be opened and shut by the lance. As the seat for this shutter is beveled, it tends on falling to wedge

itself into position, thereby making an air-tight joint. This type is used on the 2″ tube boiler. On the 4″ tube boiler the dusting panel is provided at the side casings, but there are no hinged side doors.

16. Superheater (Fig. 50)

(*a*) *Construction.* The superheater consists of *two steel boxes* lying across and on top of the boiler at the back; these boxes are connected to each other by a number of pairs of 2″ *steel tubes.* The upper box is made longer, as the pipe for the entering and superheated steam are connected to its ends. The tubes extend forward from the boxes about two-thirds the distance between the steam drum and the boxes; the rear casing of the uptake comes down at the bend of the tubes. The boxes are secured to the rear headers and to each other by channel irons and braces. The interior of the upper box is divided into three lengths by two *diaphragms* and the lower one is divided in half by one *diaphragm.*

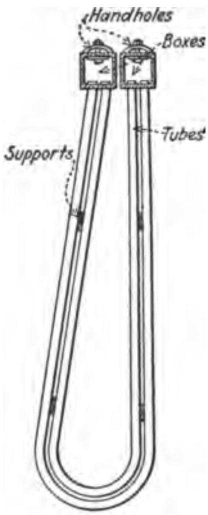


FIG. 50. Sketch of Superheater

(*b*) *Boxes.* The boxes are formed of cold drawn seamless steel tubes, ½″ thick and 6″ diameter, by heating the tubes in a producer gas furnace, using a square expanding mandrel. On the way out of the furnace the tube passes between two rollers, which give it a squared cross-section. This method is similar to that used in form-

ing the headers and cross and side boxes for the boiler. Another method of forming the boxes is to bend a flat sheet of steel into a square cross-section and then lap weld it. The first method is the best, and the one more often used. Flanged fittings are expanded into the top ends of the top box to receive the pipes for the steam and the superheated steam. In another method of construction, the ends of the top box are tapered and threaded and a flange is screwed on each end and expanded on. The holes for the tubes are drilled in a gang drill in clusters of three or sometimes four. Each group of tubes is accessible from a single handhole drilled in the opposite side of the box, just as in the case of the tubes in the boiler headers. The plates in the box handholes are interchangeable with those on the boiler headers. The length of the boxes and the number of tubes varies with the degree of superheat required.

(*c*) *Tubes*. The tubes are bent into a U-shape while cold, in a hydraulic bending machine. When the tubes are bent, they are pulled closer together at the ends than is actually required, so that when they are inserted in the box, they tend to pull together and thus keep the boxes together. The tubes are expanded in place with a pneumatic tube expander which is inserted through the handholes. The outer row of tubes is longer than the inner row, due to the nature of the construction.

(*d*) *Path of steam*. The path of the steam is from the steam drum through an expansion bend to the upper box of the superheater. The diaphragms in the boxes cause the steam to travel through the tubes four times. It finally goes out of the other end of the upper box. Another type of super-

heater construction dispenses with the diaphragms. In this type the steam enters at one end of the upper box and then passes through the tubes to the lower box, where it leaves at the opposite corner to the one at which it entered.

(*e*) *Path of gases.* When the superheater is used, the arrangement of the baffles in the boiler is as follows: the rear baffle is attached to a flame plate which slopes down from the bottom of the superheater tubes. The lower end of the rear baffle reaches to the top of the 4″ bottom tubes. A flame plate for the front baffle is attached to the back of the uptake casing, and the baffle itself extends at right angles to the tubes for about 60 per cent of their depth from the top. This arrangement of the baffles causes the gases which pass across the boiler tubes at the rear of the furnace to rise into the superheater, whence they are deflected back between the rear and the front baffles, and finally upward, and across the generating tubes for the third time, before passing up into the uptake.

(*f*) *Dusting doors.* There are dusting doors in the sides of the superheater casing, which are lagged with non-conducting material in the usual way. The top of the superheater is lined with fire tile, and then is covered over with a non-heat-conducting layer of magnesia and asbestos. The superheater casing, which is of steel plate like the boiler casing, is put on over the magnesia and asbestos.

17. Assembling of Boiler

(*a*) *Assembling headers and tubes* (Fig. 51). The headers are laid in place on an assembling table and the tubes are in-

serted in place. Both ends of the tube are expanded at the same time with a bell expander. The section thus formed is left on the assembling table and given a hydrostatic test of 500 pounds per square inch. The section is then taken from the assembling table by means of a travelling crane

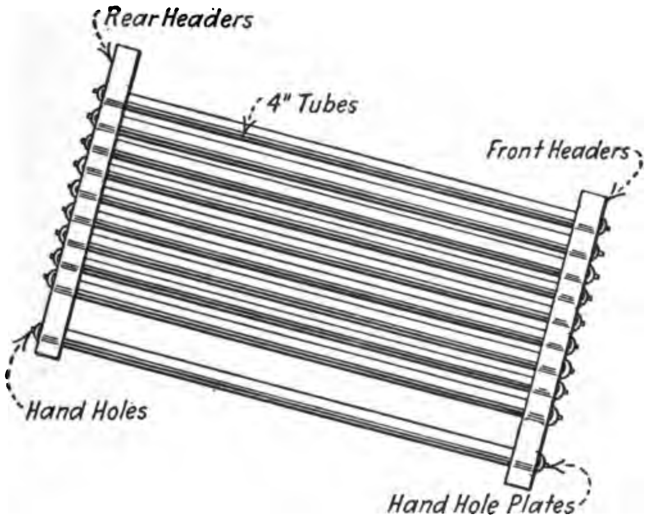


FIG. 51. Section of Tubes and Headers after Being Tested

and given a bath of fish and linseed oils, to prevent corrosion during transportation.

(*b*) *Method of leveling tops of foundations.* The tops of the foundations are leveled by steel tape measurements from the erection floor. These measurements are then checked up by means of a spirit level.

(*c*) *Method of assembling foundation, sections, etc.:*

(1) *Side and back plates.* The sheet steel side and back

plates are bolted and riveted to the angle irons, I-beams and channel irons.

(2) *Ash pan.* This is made a part of the casing and is constructed of boiler plate steel. It is made up in two sections, the flanges of which are bolted together at the center, and riveted to I- and channel beams at the ends.

(3) *Furnace fronts.* These are riveted at the top and bottom to angle irons and at the sides to I-beams.

(4) *Header supports.* A horizontal I-beam supports the rear headers. This is bolted to the rear water legs and these are fastened to channel irons or vertical I-beams. The front water legs or uprights support the front cross-boxes, and these in turn support the front headers. These water legs rest on either channel irons or vertical I-beams to which they are fastened by vertical holding down bolts. In boilers having no water legs, the mud-drums or front cross-boxes rest on supports which are bolted to the I-beams, the mud-drums being allowed freedom to move.

(5) *Downcomer nipples.* The downcomer nipples are expanded aboard ship. The ends in the steam drum are expanded first. The ends in the top of the front header are expanded afterwards. In expanding the header ends of the nipples, the second handhole plate from the top of the header is taken off and the expanding tool inserted. The mandrel is then inserted and the nipples are rolled in.

(6) *Assembling section.* The section (Fig. 51), consisting of front headers, tubes, and rear headers, is laid on the foundation with a traveling crane. Shims are placed between the foundation and the front header to get it to

the proper elevation above the cross-boxes. Care is taken that the rear header will be free to move as it contracts or expands.

(7) *Flame plates.* The flame plates are in steel sections. They are inserted as explained above in paragraph 13 (Flame and Baffle Plates).

(8) *Steam drum support.* The steam drum is supported at the bottom by the supporting sleeves around the downcomer nipples, or in some cases by the downcomer nipples themselves. At the rear, the circulating tubes, expanded into the drum, help to support it.

(9) *Circulating tubes.* The circulating tubes are secured on board ship. They are expanded at one end into the steam drum, and at the other into the back headers or in some cases into a cross-box at the rear.

(10) *Lining up the steam drum.* The steam drum is lined into place by steel tape measurements taken from the erection floor.

(11) *Dimensions of downcomer nipples.* Part of the downcomer nipples extend into the steam drum. Both ends are expanded into the holes by means of a universal mandrel. They are 4″ in diameter, 12½″ long, and have 9½″ exposed to the gases.

(12) *Casing.* The casing is made up of ¼″ sheet steel, and is secured by bolts and rivets to angle irons, I-beams, and channel irons. The riveting of the sections to the supporting irons is done by means of a pneumatic hammer.

QUESTIONS

1. How is the steam drum of the B. & W. boiler formed?
2. Name seven internal steam drum fittings.
3. Where is the fusible plug located and how is it put in?
4. What is the purpose of the dry pipe?
5. Name the external steam drum fittings.
6. Explain how the headers are constructed. How are the ends closed?
7. What kinds of tubes are used in B. & W. boilers?
8. Where are the downtake nipples located and what is their purpose?
9. Where are the bottom blow connections fitted?
10. What is the form of the side boxes and how are they constructed?
11. When are side boxes used?
12. Describe the furnace of a coal burning boiler. How does it differ from the oil burner?
13. What is the purpose of the flame and baffle plates?
14. What filling is used between headers?
15. Where are the dusting doors located and what are they used for?
16. Discuss the superheater, with special reference to the construction, the boxes, the tubes, the path of the steam and the path of the gases.
17. How are the headers and tubes assembled?
18. How are the tops of the foundations leveled?
19. How is the steam drum supported?

SKETCHES

1. Draw a rear view of a steam drum, B. & W. boiler, showing the 4″ holes for the circulating tubes, the butt strap joint, etc.

2. Sketch a drum head, showing manhole openings.
3. Sketch the following internal drum fittings; umbrella feed; baffle plate; dry pipe; and swash plate.
4. Draw a front view of the B. & W. steam drum showing external fittings.
5. Sketch a header, showing square handhole openings.
6. Sketch the bottom part of the casing, showing a water leg.
7. Sketch a cross-box.
8. Show by means of a sketch, how the side boxes are connected.
9. Sketch the interior of an oil burner furnace.
10. Sketch a side door, showing dusting slides.
11. Sketch a superheater showing boxes.
12. Make a cross-section sketch of a B. & W. oil-burning boiler.

LESSON 5 — EXPRESS BOILERS

1. General Characteristics of Express Boilers

(*a*) *Form of boiler.* In these boilers, the tubes are nearly vertical. They are all of the accelerated type of circulation. Moreover they are all of the small tube type (2″ or less). Express boilers generally consist of a steam drum connected by means of nearly vertical tubes (either straight or curved) to two or more water drums. Tubes are generally of the drowned type — that is they discharge below the working water level. In some types of Express boilers, *downcomers* are fitted between the steam drum and the water drums. These are tubes of fairly large diameter and are fitted farthest away from the fire. In large boilers, two or more downcomers may be fitted to each water drum. Where they are fitted the water flows down from the steam drum to the water drums through the downcomers and up through the small tubes. They improve the circulation, especially when the ship is rolling and pitching. A large percentage of all Express boilers are now equipped as oil burners.

(*b*) *Water circulation.* Where downcomers are not fitted, the circulation is rather uncertain, varying with the roll of the ship and also with the different rates of combustion. In general the water passes down from the steam drum to the water drums through the tubes farthest away from the heat and up through the hottest tubes.

(*c*) *Gas circulation.* The hot gases are generally compelled

to pass across the tubes several times by means of baffles and flame plates.

(*d*) *Where used.* Express boilers are used wherever a quick acting boiler is a necessity. They are adaptable to forcing and overloads and their use is standardized in naval destroyers.

2. Characteristics of Special Makes

(*a*) *Yarrow boiler.*

(1) *Construction.* The Yarrow boiler has a steam drum and two water drums. The water drums are oval in cross-section. The tubes are straight and are expanded into each drum. After steaming the tubes become curved, due to the action of the heat. In some Yarrow boilers, downcomers are fitted outside of the boiler casing while others have no downcomers. In some instances, the tubes are given a slight curvature where they enter the drums, so that they will enter at right angles to the drum. The steam drum is made of two sheets, butt-jointed and fastened with double butt straps. The lower (tube) sheet is made heavier, but is planed down between the tubes to reduce the weight. The water drums are also made in two pieces. The boiler casing is made of galvanized steel plates, insulated from the heat by means of fire brick, asbestos board and magnesia.

(2) *Circulation of water.* The tubes farthest from the heat carry the water to the lower drums while the hotter tubes carry the water and steam to the steam drum. As mentioned above, the water circulation is uncertain when the ship is pitching and rolling heavily. If downcomers

are fitted the water passes down through these to the water drums and up through the tubes.

The feed water enters the upper drum. Since the inner tubes get hot first, the water will come down through the outside ones.

(3) *Path of gases.* The usual method of baffling the gases is to put a baffle at the upper end of the tubes, on the outer side, in order to direct the gases down through the tubes. A flame plate is put in at right angles to the tubes and at about half their length. The opening of the uptake has a restricted area in order to retard the gases. The result of this system of baffling is to allow all the tubes to get their share of the heat.

(4) *Advantages.* The Yarrow boiler is simple and efficient.

(5) *Disadvantage.* Certain tubes are very hard to replace and necessitate removing a large number of others.

(*b*) *White-Forster boiler.* (Figures 52 and 53.)

(1) *Construction.*

(*a*) *Water drums* (Fig. 54). These are of open hearth steel, hot pressed in one piece, and are machined down from $1\frac{1}{4}''$ thick to $\frac{7}{8}''$. They are left $1\frac{1}{4}''$ at the tube sheet. The drum is riveted by means of a hydraulic bull riveting machine. The shell is held by means of a double riveted, double butt strap joint. Before any tube holes are drilled, the water drums are given a hydraulic test of 400 pounds per square inch, and are caulked while under pressure. The holes for the tubes are drilled on a special gang drill, which bores them at the proper angle. These holes are then reamed out

with a portable pneumatic reamer, and the burrs are removed with a rat-tailed file. The water drums, sometimes referred to as mud-drums, are placed high above

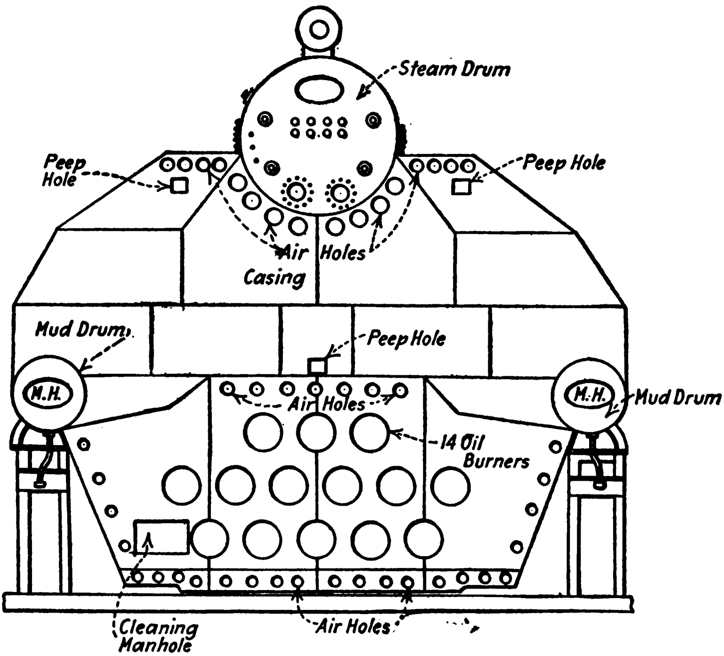


FIG. 52. Boiler Complete Showing Casing and Number of Furnaces in Detail — White-Forster Boiler

the furnace, in order to allow sufficient furnace volume to get complete combustion.

(*b*) *Steam drum* (Fig. 55). The steam drum is made up of two sections. The tube section is two inches thick. It is machined down at the ends and sides to $\frac{7}{8}''$ thickness. The reason for this is to facilitate the

making of a joint with the other section, which is only $\frac{7}{8}''$ thick. The holes for the tubes are drilled on a gang drill before the sections are assembled. They are

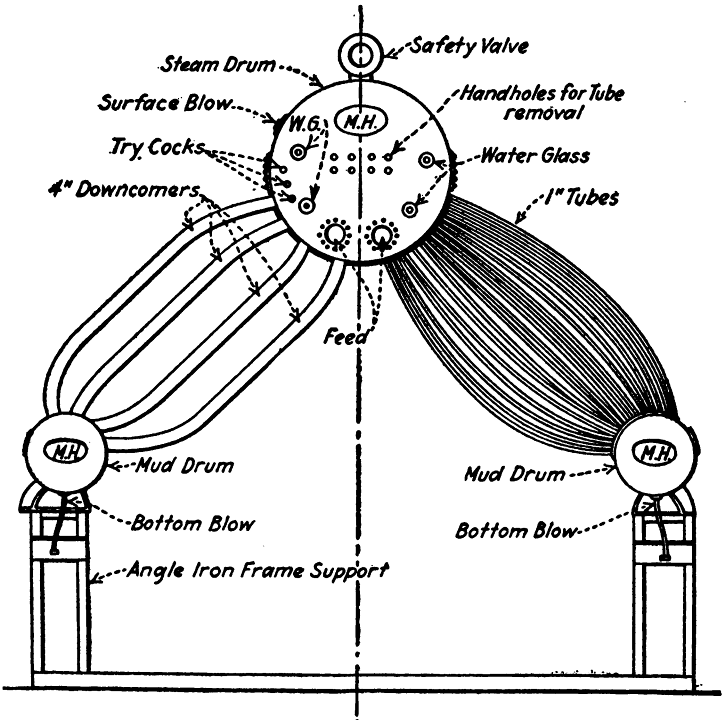


FIG. 53. Boiler Detail before Installing Casing, White-Forster Boiler

reamed out with a portable pneumatic reamer. The pilot holes for the butt straps are drilled with a pneumatic drill. The joints connecting the two sections of the shell are double butt strap joints, having six rows of rivets. Where the two halves meet a ten-

inch bevel is cut and this is welded with an oxy-acetylene flame. When all the holes have been drilled, the shell is riveted on a bull-riveter. After this has been

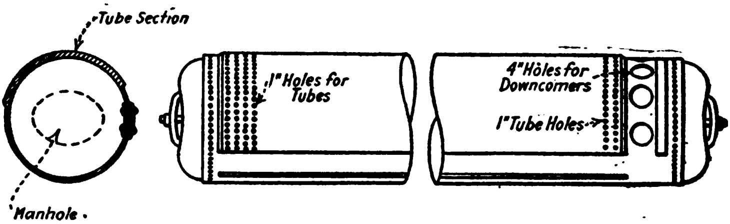


FIG. 54. Mud Drum in Detail, White-Forster Boiler

done, the heads are put in and the rivet holes are drilled clear through. The heads are then removed and the burrs cleaned off. The heads are again replaced and

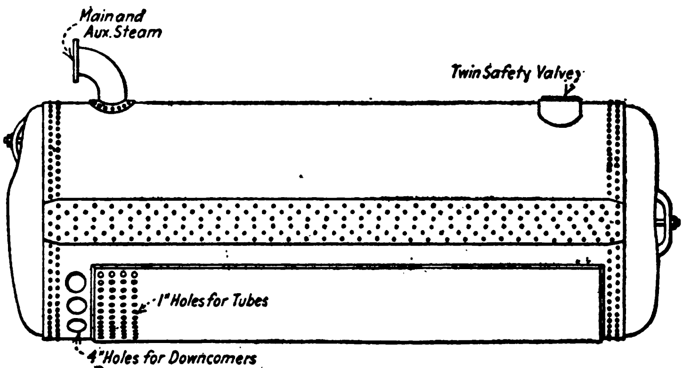


FIG. 55. Side View of Steam Drum, White-Forster Boiler

the front head (Fig. 56), which has a manhole in it, is riveted first. Then the other head is riveted through the manhole of the first head. This riveting is done on a hydraulic bull-riveter.

(*c*) *Downcomers — rear and front.* In the usual construction, two large downcomer tubes are fitted, connecting the rear steam drum head with the rear head of each water drum. In another type of construction, the downcomers are in front, and connect the shell of the steam drum to the shells of each water drum. In

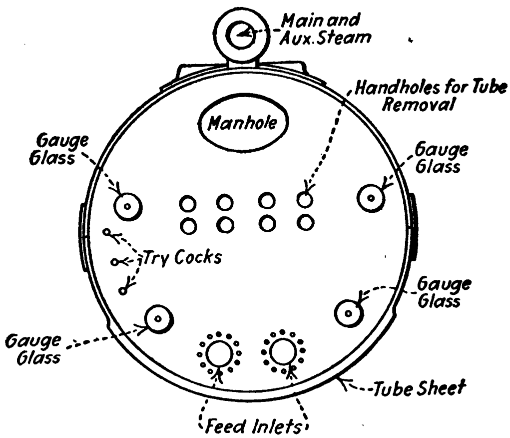


FIG. 56. Front View of Steam Drum White-Forster Boiler

this case, there are eight downcomers, each of 4″ diameter (Fig. 53).

(*d*) *Tubes.* The tubes all have the same curvature, and this is of slight degree. They are made of cold drawn seamless steel, 1″ in outside diameter, and $\frac{1}{8}$″ thick. They have a maximum length of 8′ 1″ and a minimum length of 7′ 2″. There are 24 different lengths of tubes used, 3744 tubes being the total number on the boiler. The burrs are taken off the tubes

in a lathe, and they are then bent between rollers on a hydraulic bending machine. They are then tested on a testing table for proper curvature. Any alterations in curvature are made by hand. They are then given a hydraulic test at a pressure of 450 lbs. The tubes are upset at one end for a distance of 4″ from the end. This end fits into the steam drum. Hence the holes in the steam drum can be made a trifle larger than those in the mud-drum. This gives clearance for inserting (and also for removing) the tubes, which are put in through the manhole and then through the tube holes in the steam drum. They are then guided to the corresponding holes in the mud-drum. Both ends of the tubes are expanded at the same time by a pneumatic expander. A tapered mandrel is then driven into the ends of the tube in order to flare them. This operation is known as *belling*. To remove a tube, a slot must be cut in the end within the mud-drum. The tube must then be collapsed inward with an oyster knife. This operation must then be repeated within the steam drum. The tube can then be removed through the manhole in the front head of the steam drum.

(*e*) *Baffles*. Baffles are fitted above the tubes near the uptake in such a manner as to distribute the gases evenly over the tubes and also to make them cross the tubes at right angles.

(*f*) *Casing*. The boiler has an inner casing of galvanized iron $\frac{3}{16}$″ thick. The furnace side is coated

with asbestos. The outer casing is also of galvanized iron $\frac{1}{8}''$ thick.

(2) *Circulation of water.* The water passes down through the downcomers at the rear of the steam drum to each mud-drum and then passes up through the small tubes.

(3) *Path of gases.* The gases pass across the tubes at right angles, being drawn across the entire tube surface and then passing up through the uptake. The purpose of the baffles is to distribute the gases evenly. The circulation of the gases is very poor in this boiler.

(4) *Advantages.* The White-Forster boiler is of simple construction and the slight curvature of the tubes is an advantage. Moreover the tubes are easily removed and replaced and they can be cleaned both internally and externally.

(*c*) *Normand boiler.*

(1) *Construction.* The steam drum is made in two sections joined by triple riveted lap joints. There is a manhole in the front head and one in the rear of the drum on the top of the shell. A handhole is located in the rear head. There are two water drums. Instead of having a dry pipe in the steam drum, a steam dome is located on the top of the drum. There are four downcomers in this boiler, two larger ones at the rear and two smaller ones in the front. These are situated outside of the casing and act as wet legs. They allow free circulation from the steam drum down to the water drums.

The downcomers are expanded in the drum shells. The small downcomers, connecting the front of the

steam drum with the front of the water drums, serve primarily to help support the steam drum.

The tubes are curved, but not excessively so, and enter the drums at right angles.

The Normand has a large ratio of heating surface to grate surface — 38 to 45 square feet of heating surface per square foot of grate surface. In oil burners, the ratio is approximately 14.4 square feet of heating surface per cubic foot of furnace volume.

(2) *Circulation of water.* The water passes down through the rear and front downcomers to the water drums and comes up to the steam drum again through the small tubes.

(3) *Path of gases.* The first and second outer rows of tubes interlock and form a wall, leaving an opening for the gases only at the upper part, and for about one-third the length from the front. The inside tubes also interlock to form a wall, for two-thirds of the way back and leave an opening for the gases only at the rear. Hence the tubes themselves are the baffles which direct the gases. The gases are compelled to go to the back of the furnace, then rise upward and return (mixing between the tubes) to the front of the boiler. About one-fourth of the way from the front of the boiler, the gases are deflected downward by a baffle and then they again rise and pass to the uptake through the opening at the upper end of the outer tube wall.

(4) *Advantages.* The gas circulation is better than in other types of express boilers and moreover the Normand

boiler also has the highest ratio of heating surface to grate surface. The Normand has about 70 per cent more heating surface per cubic foot of furnace volume than the Yarrow boiler. The main disadvantage is that if a tube which happens to be in a nest of tubes has to be removed, it is necessary to take out eight or ten others. In the Yarrow, four or five others must be taken out, while in the White-Forster no other tubes have to be removed.

(*d*) *Thornycroft boiler.*

(1) *Construction.* In the latest types of Thornycroft boilers there is a steam drum and two water drums. The steam drum is made in two sections held by double butt strap butt joints. There is a manhole in the lower portion of the front head, and a handhole in the upper part. The tubes are nearly straight, being curved at the ends, so as to enter the drums normally. They are expanded into the drums. There are two downcomers at the front of the steam drum connecting to the front of the water drums. The downcomers are outside of the casing. In some types, the downcomers are at the rear instead of the front of the boiler. They are expanded into the shells of the steam and water drums. In the older types of Thornycroft boilers the curvature of the tubes was quite large, and they entered the steam drum through the steam space. All Thornycroft boilers are now constructed with drowned tubes.

(2) *Circulation of water.* The water passes down through the downcomers from the steam drum to the water drums and then back to the steam drum through the tubes.

(3) *Path of gases.* The gases pass directly across the tubes to the uptake, no baffles being used to divert them or to increase the efficiency of the circulation.

(4) *Advantages.* The improved types of Thornycroft boilers are fairly efficient and the removal of tubes is no more difficult than in the Yarrow. Nevertheless, it is not in high favor in the U. S. Naval service at the present time.

QUESTIONS

1. State the general characteristics of express boilers, with special reference to form of boiler, water circulation, and gas circulation.
2. For what uses are express boilers especially fitted?
3. Describe, in a general way, the construction of the Yarrow boiler.
4. Describe the construction of the White-Forster boiler.
5. Where are the baffles fitted in a White-Forster boiler?
6. What are the advantages of the White-Forster boiler?
7. How does the Normand boiler differ from the Yarrow boiler?
8. What are the advantages of the Normand boiler?
9. Describe a modern Thornycroft boiler, with special reference to construction, circulation of water, path of gases, and advantages.

SKETCHES

1. Sketch the steam drum of a White-Forster boiler (side view).
2. Sketch the mud-drum of a White-Forster boiler.
3. Show a front view of the steam drum of a White-Forster boiler.
4. Sketch a front view of a White-Forster boiler before installing casing.
5. Sketch a front view of a White-Forster boiler, showing casing and number of furnaces in detail.

LESSON 6 — BOILER FITTINGS

1. Fittings in Steam Part of Boilers (Steam Fittings)

(*a*) *Dry pipe.* A pipe located in the highest part of the steam space, which extends nearly the full length of this space. It is made of thin metal, of the same grade as the shell. Either round or square holes extend along the length of the pipe on the upper side. The total area of the holes should be one-third greater than the cross-sectional area of the pipe itself. The *purpose* of the dry pipe is to collect *dry steam* to supply the main steam line.

(*b*) *Main stop valve.* This is ordinarily a globe valve, connected to the dry pipe, either in the middle or at either end. It is a large heavy casting of composition, gun metal or cast iron. The valve should be so arranged that the stem stands vertical, because with this arrangement it is easier to repair, does not wear so fast, and it also finds its seat better. The *purpose* of the main stop valve is to control the supply of steam going to the main engine. An *auxiliary stop* valve is commonly fitted to supply steam to the auxiliaries. The later method is to use only a main stop valve. The two valves may be found in one or in separate bodies. Sometimes two dry pipes are fitted, one for the main steam line and one for the auxiliary line. Sometimes the main stop valve and the safety valve are made in one fitting. Parts subjected to pressure are never cast but are always made of steel or wrought iron.

(*c*) *Safety valves.* Spring loaded safety valves are now universally used. The safety valve is the most important valve on the boiler. In connecting up the safety valve, there must never be any valve fitted which can shut off the safety valve from the boiler. There should never be any valve situated on the atmosphere or exhaust side of the safety valve. The safety valve should be set at the highest pressure, which the boiler is intended to carry. To set the safety valve, put steam pressure under the valve, watching a gauge which has been tested out. By slacking off or tightening the compression nut, which controls the spring adjustment, the tension of the spring can be brought to the desired amount. The adjustment of the cuddling ring controls the pressure at which the valve will re-seat. Control is obtained by adjusting this ring up or down. The purpose of the safety valve is to keep the pressure in the boiler down to the desired amount and to allow a means of escape for excess steam. There are always at least two safety valves fitted per boiler.

(*d*) *Air cock.* This is found on many boilers and is located in the highest point, in the steam space of the boiler. Its purpose is to get rid of air and it should be left open in getting up steam.

(*e*) *Steam gauge.* This fitting is attached by a small diameter pipe to the highest point in the steam space. The most common type of steam gauge is the U-tube type. The water in passing into this tube has a tendency to straighten it out. The tube is made of an alloy which is highly tempered. In installing the gauge it is necessary to have water in the

tube rather than live steam. To accomplish this, a circular loop is made in the pipe leading to the gauge and this forms a siphon. A drain cock is fitted at the gauge and another cock is often fitted near the boiler. The cross-section of the U-tube is elliptical. The gauge casing is of brass or of brass, nickel plated. A steam gauge, or sometimes two gauges, are fitted to each boiler. The gauges must alway be kept open to the boiler. The purpose of the steam gauge is to indicate the correct pressure being carried in the boiler.

2. Fittings in Water Part of Boiler (Water Fittings) (*a*) *Gauge glasses and connections* (Fig. 57). The height of the glass depends upon the type of boiler. The bottom of the glass should not be less than $5\frac{1}{2}''$ above the highest heating surface in the Scotch boiler. Two glasses are usually fitted on the Scotch boiler at the sides, near the front, so that the firemen and water tender can always know the level of the water. Sometimes glasses are fitted in the front and back also. Sometimes, in fire tube boilers, a water column, or stand pipe, is used, which connects at the top into the steam space of the boiler and at the bottom into the water space. The gauge glass is fitted at the proper level in this column. In

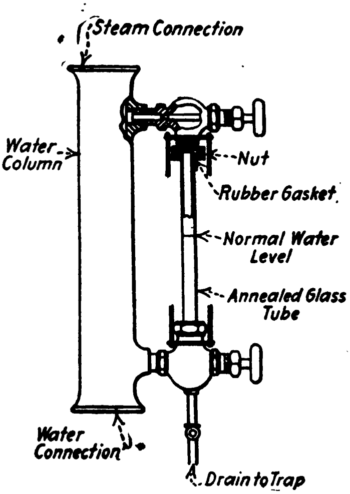


FIG. 57. Cross-section of Gauge Glass

the water tube boiler, the gauge glasses are placed on the shell of the steam drum, on either side of the try-cocks, and at a level, such that the middle of the glass is about in the same plane as the middle of the drum. The glasses are connected directly by means of the gauge mounting to the shell. The gauge mounting is a combination of a stuffing box and a valve. The reason for the use of two or more glasses is mainly to enable the water tender to determine an average level when the ship is rolling and incidentally to allow for an emergency reading when one glass bursts. The gauge glasses are made in the form of tubes, of about $\frac{5}{8}''$ diameter and from 12 to 18″ long, of Scotch glass, capable of withstanding high-pressure. Three cocks are usually fitted to each water gauge, one at the top of the glass to shut off the steam, one at the bottom to shut off the water, and another one at the bottom connected by a small pipe to the bilge, and used as a drain. To replace a broken gauge glass, first take the nuts off, placing them in a bucket of cold water. Then scrape the gaskets off the nuts and get rid of the pieces of glass. Then insert glass, first in the upper cock, then in the bottom, taking care not to let the glass touch at the top or bottom. Then set up on the top nut and afterwards on the bottom. Make these hand tight only and then slack up a bit on the bottom one. Next crack a little steam through the top cock with the drain left open. Warm up the glass gradually, keeping the drain open till the glass is hot, then close the drain and allow the water to rise in the g'ass. One reason why the blowing out of gauge glasses is such a common occurrence

on some ships is because of the practice of cutting the glass to length by hand. The life of the glass will be much increased if it is fire finished. Other types of gauge glasses which have been developed are the window or plate water glass and the Klinger reflex water glass. In these gauges, the water passes between plates instead of through a tube. In the Reflex type only *one* plate of glass is used. An objection to this type is that the expansion of the composition and the glass very often differ to such an extent as to cause breaking of the glass.

(*b*) *Try-cocks.* These furnish a most important auxiliary means of determining the level of the water in the boiler. They are screwed directly into the shell. The lowest try-cock should be not less than $4\frac{1}{2}''$ above the highest heating surface, in the fire tube boiler, except in the case where four are used in a set, in which case the lowest is then placed directly level with the top of the combustion chamber. There should be at least two sets of these try-cocks on all boilers and there should be three to a set. They should be placed a distance of $4\frac{1}{2}''$ apart (measured on a vertical line). They are placed on the shell of the steam drum at about the center, in the water tube boiler, in such a position as to indicate highest and lowest safe limit.

(*c*) *Feed valves and internal feed pipe.* The feed stop check is a combination of two valves in one casing. The stop valve is located between the check and the boiler, so that repairs may be made to the check valve, while the boiler is under steam. The feed pressure must exert a greater pressure than that of the boiler before check valve can be opened.

All boilers must have two separate means of water feed — main and auxiliary — and both have the same kind of valves. The checks should be used to regulate the feed as they are designed for this purpose. The use of the stop will tend to wear out the valve seats and hence it is much better to keep the stop wide open. The stop valve could be used for regulation, in an emergency, however. The feed valves are connected to internal feed pipes, one for the main feed and one for the auxiliary feed. In the Scotch boiler these extend the length of the boiler, above the tubes, and have openings so arranged as to discharge the feed upwards towards the steam space. In water tube boilers, the feed enters at the steam drum, the main valves being located on one drum head, and the auxiliary valves on the other. The feed is directed in the same direction as the descending current, either by the internal feed pipe, or by a special fitting, such as the "umbrella feed" used in the B. & W. boiler.

(*d*) *Surface blow.* This valve, which is usually an extra heavy globe valve, is connected with an internal pipe, which in turn is fitted at its end with a scum pan, just below the normal water level. The other end of the surface blow connects by means of piping to a sea valve. This surface blow is used to remove scum or grease from the surface of the water.

(*e*) *Bottom blow.* This valve should be of the sliding piston type. The globe valve is not a suitable one for a bottom blow, although it is sometimes used. The use of this valve is to remove any sediment or solid matter from the water.

It may be used to blow out brine in case the density of the water is too high. In water tube boilers, the use of the bottom blow is especially necessary to remove the mud and sediment from the boiler. The bottom blow can be used, after the steam is off the boiler, to pump water from one boiler to another, or into reserve feed tanks or even over-board if required. Another possible use in the fire tube boiler is as an aid to circulation when getting up steam.

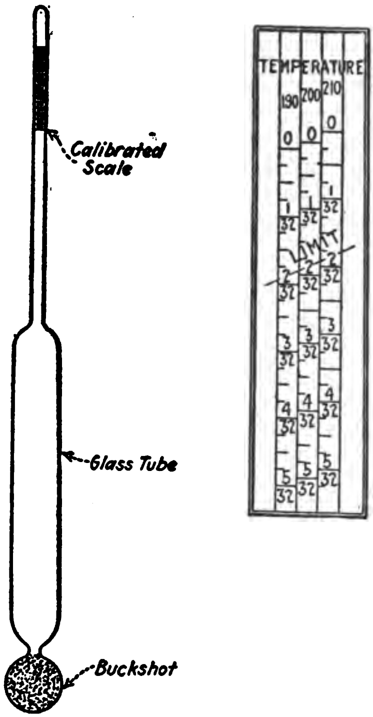


Fig. 58. Salinometer

(*f*) *Hydrokineter*. This is a device, consisting of an arrangement of steam nozzles used only on fire tube boilers, when getting up steam, to compel circulation of the water. It works on the principle of the injector, using steam from another boiler and is never used after steam is up.

(*g*) *Salinometer cock*. This is an asbestos packed cock, placed low down in the water space and used to draw off water. The sample of water is tested for its degree of salinity (saltiness) by means of a hydrometer which in this case is called a salinometer (Fig. 58).

(*h*) *Drain cock.* This is located in the lowest point of the water space and is used to drain all the water out of the boiler, if so desired. It may be a plug cock or a valve.

QUESTIONS

1. Where is the dry pipe located in a Scotch boiler? Where in a B. & W. boiler? What is its purpose?
2. What is the best way to fasten valves to a fire tube boiler?
3. Name the various fittings in the steam part of the boiler.
4. Name the various fittings in the water part of the boiler.
5. Describe each fitting, giving its location and use.
6. What is the most important valve on the boiler?
7. What is a usual type of valve for the bottom blow?
8. Where should the steam gauge be located?
9. What precaution must be taken in installing a steam gauge?
10. What type of gauge glass is most commonly used?
11. Name another type of gauge glass.
12. What is the purpose of the "cuddling ring" in a safety valve?
13. Where should the lowest try-cock be located on a fire tube boiler?
14. How far apart are the try-cocks usually placed?
15. Which valve is located nearer the boiler, the feed check or the stop? Why?
16. Are stop valves arranged to open or close against pressure? Why?

SKETCHES

1. Sketch a cross-section of a gauge glass.
2. Sketch a salinometer. Make an enlarged sketch of the calibrated scale.

LESSON 7 — FIRE-ROOM ACCESSORIES

1. Coal Burning

(*a*) *Tools.* List and functions of tools used by fireman:
Shovel, to fire furnace and to handle ashes.
Slice bar, to slice fire and break up clinkers.
Small hoe, to spread fire.
Large hoe, to clean fire.
Devil's claw, to remove pieces of clinker.
Lazy bar, placed across furnace front to rest slice bar or large hoe on.
Pricker bar, used with lazy bar to open air space.

The most important tools mentioned above, are the slice bar, the shovel and the hoe.

The water-tender should have a small box of hand tools including a hammer, chisel, monkey wrench, grommets, water glasses, graphite and tallow, red lead, file, scrapers and chipping hammers. He should be able to take care of any ordinary overhauling or odd jobs in the fire-room.

(*b*) *Time firing device.* This is usually an electrically operated signal, consisting of a bell and light, which operates at regular intervals, telling the fireman when to coal or to work the fire. The time interval may be regulated, and should be determined for each particular case. As an illustration of how this device might be worked, consider a case of a water tube boiler with four furnaces. Suppose that the device is set to signal every $1\frac{1}{2}$ minutes. The

fireman coals the furnace at the right. At the next signal he coals the furnace to the left of that and so on until he fires the furnace at the extreme left. Thereafter, by going back to the furnace on the right and proceeding the same manner as at first each furnace would be fired at 6-minute intervals. Here the spreading system is referred to. In the case of a Scotch boiler, with say three furnaces and using the coking system, at one signal one furnace would be coaled, at the next signal the second furnace would be sliced, and at the next signal the third furnace would be hoed (coal would be shoved back). The furnace which was coaled would then be sliced at the next signal and a similar rotation carried out for each furnace so that with a signal every 5 minutes, each furnace will receive a fresh charge of coal every 15 minutes. The water tender must use his judgment as to the number of shovelfuls at each charge.

(*c*) *Ash handling apparatus.*

(1) *Ash ejectors.*

(*a*) *Above water discharge.* In most ejectors of this type, the ashes are dumped into a hopper and they are carried up a cast iron pipe by the action of water under pressure. A heavy duty pump of duplex type is used and the water is introduced through a nozzle so that a jet is formed in the center of the pipe. This method of discharging ashes has given very good results.

(*b*) *Below water discharge.* In this type, the ashes are discharged below the water line either by hydraulic or pneumatic action (water or air under pressure). These systems have not given very satisfactory results in all

cases, but the claim is made that if the ashes are discharged below the bilge keels, no trouble will be experienced as to clogging of the main injection.

(2) *Ash hoist and ash buckets.* The ash hoist may consist of a small double cylinder engine having a differential reversing valve. In some cases, the hoisting engine consists of a long, small diameter steam cylinder, having two ports, one at the top of the cylinder and one at the bottom (Fig. 59). These are connected by piping to a cock, operated by a lever, and so connected, that in one position the steam will pass into the top port and the bottom port will be open to exhaust, while when the lever is turned, the bottom port will be open to live steam and the top port will be open to exhaust, or the steam may be shut off altogether by the lever. In this manner reversing is accomplished. One stroke of the piston is sufficient to lift the ashes from the fire-room floor to the point where they are emptied overboard through a chute in the side of the ship. The top of the piston is connected to block and fall, using a differential pulley, by means of a wire rope which leads down to the fire-room.

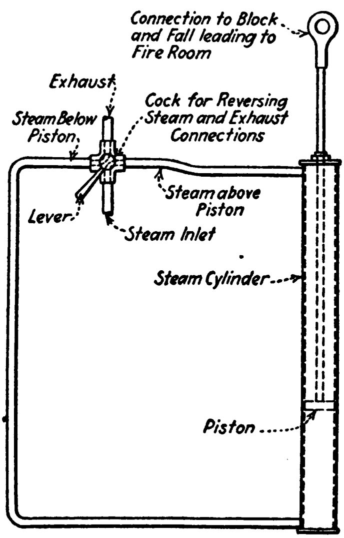


FIG. 59. Ash Hoist

The ashes are generally hoisted through a circular tube, about 2 feet in diameter, extending from a short distance above the fire-room floor to the level of the main deck. Where this tube is used for a ventilator, it is extended upward to form a seating for the cowl, and a door is put in for getting the buckets from the tube.

Another type of hoist is the electrical driven ash hoist. In all types the stopping is automatic, to prevent over-hoisting. In some cases a voice tube and gong are fitted between the stoke hold and the hoisting platform.

Ash buckets are round cylindrical iron buckets having extra heavy bottoms and they have an arrangement of a ball pivoted in pads at each side so that the bucket will tend to right itself automatically when the hook of the ash hoist is engaged with it. These buckets hold from 75 to 100 lbs.

(*d*) *Coal buckets.* These are cylindrical iron buckets with extra heavy bottoms with handles riveted on the sides near the top. They carry about 35 pounds of coal.

2. Oil Burning

(*a*) *Heaters.*

(1) *Necessity for heating oil.* This is necessary in order that the oil will flow with greater ease, and also that its viscosity will be reduced enough to get good atomization and a maximum capacity from the burners.

(2) *Types of heaters.*

Horizontal surface type. In this type the oil circulates

through the upper row of tubes and returns through the lower rows, while steam passes around the tubes. The tubes are contained in a cylindrical shell and are expanded into the tube sheets. One tube sheet is so connected to the shell, that the tubes are free to expand. This type is sometimes called the "Straight flow type" and is similar in construction to a condenser.

Film heater. In this type the oil enters at the bottom and is forced between an inner and an outer corrugated copper tube, while steam enters at the top, and passes outside of the outer tube and inside the inner tube. By this means, the oil is spread into a thin film, which receives heat from the steam on both sides. The steam passes out through the bottom.

Coil heaters. These are similar to feed water heaters and will be described later.

These heaters take steam from the auxiliary steam line. They usually drain to the hot well through traps These traps should be watched for oil leaks to prevent oil from getting into the feed. The oil should be heated to about 150° Fahrenheit although this will vary with the grade of fuel used. Care should be taken not to heat the oil to the flash point.

(*b*) *Strainer.*

(1) *Use.* To prevent dirt and grit from choking burner openings and getting into pumps.

(2) *Location.* Strainers are sometimes located in the suction and discharge pipes of the oil pumps. One arrangement of strainers is given below:

Settling tank ⟶ Service Pump X ⟶ Strainer No. 1 V ⟶ Heater H ⟶ Strainer No. 2 V ⟶ Air Chamber ⟶ Burner through Strainer No. 3

(3) *Description.* They usually consist of two baskets of wire gauze so arranged that one can be by-passed while it is being cleaned and the oil passed through the other one.

(4) *Cleaning.* To clean the strainers, the basket is removed and a jet of steam is blown through the gauze.

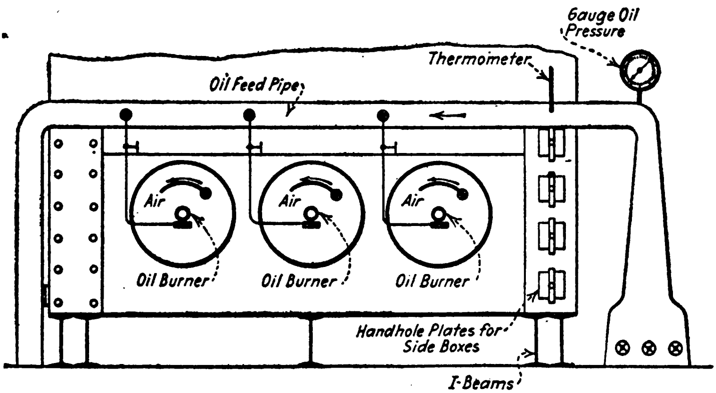


FIG. 60. Sketch of Furnace Front and Burners, B. & W. Boilers

(*c*) ***Burners*** (Fig. 60):

(1) *Function.* Atomization of the oil so that it becomes intimately mixed with air required for complete combustion.

(2) *Types.*

(*a*) Mechanical (Fig. 61).

(*b*) Inside mixing — air or steam

(*c*) Outside mixing — air or steam

(3) *Operation of mechanical burner.*

(*a*) *Air pressure.* In the closed fire-room system, the air pressure may be carried as high as 6″ of water (1″ by gauge, head of water equals 5.34 lbs. per sq. ft.). In some cases only 2″ or 3″ is necessary. Successful mechanical atomization has also been developed, using natural draft.

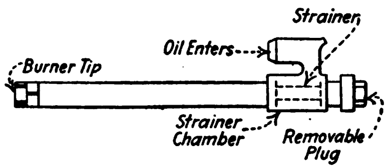


FIG. 61. Sketch of Oil Burner

(*b*) *Capacity.* Individual burners have been found to have a maximum capacity of about 100 H.P. per burner.

(*c*) *Viscosity of oil.* Best results for a number of different oils tested were obtained at a viscosity of 8 Engler. Further reduction in the viscosity did not increase the burner capacity.

(4) *Advantage of mechanical burner.* They can be more readily adjusted than the other types under wide changes of load. They are more economical than steam burners and moreover there is no loss of feed water.

(*d*) *Air register.*

(1) *Use.* To regulate the velocity and the quantity of air (in conjunction with the blowers) and in some types to give the air a whirling motion.

(2) *Types.*

(*a*) *Conical.* This type usually has an adjustable outer sleeve which will allow the air to be shut off entirely or the opening to be adjusted to any desired amount.

(*b*) *Discal.* Impeller plates are used, with fixed openings, and air regulation is obtained by draft doors on

the furnace front. The air is given a whirling motion by the impeller.

(*c*) *Cylindrical.* These are similar to the conical registers, although some of this type have no provision for giving the air a whirling motion.

(*e*) *Booster pumps.* These are light service oil pumps, used for the purpose of pumping oil to or from the storage tanks, for loading oil from another vessel or for pumping direct to the service pump suction.

(*f*) *Oil service pumps.* These are heavy duty pumps used to bring the oil to the required pressure (about 200 pounds. per sq. inch) and to send it through the heater to the burners.

(*g*) *Oil storage tanks.* These tanks sometimes have a capacity of 5000 gal. They are fitted with heating coils at the bottom, for reducing the viscosity of the oil; also with glasses at the top and bottom to show oil level and water level respectively; with a drain cock for drawing water off the bottom of tank. There is a vent pipe fitted which leads from the tank top to the main deck. The filling connection is at the top and the suction at the bottom.

(*h*) *Settling or separation tanks.* Oil is pumped from the storage tank to the settling tank by means of the booster pump. These tanks contain about 20 tons (about 12 hours' supply) and furnish the oil to the service pump. A coil of piping, heated by exhaust steam, is floated near the surface of the oil, and this heating sends the lighter oil to the top and the heavier water to the bottom, where it is drained off by means of a drain cock. Vents and other fittings are

supplied as in the case of the storage tank. The settling tank is often made to perform the function of a meter.

3. Feed Heaters

(*a*) *Advantages of feed heating:*

(1) *Increase in boiler efficiency.* The boiler, as a means of utilizing the heat in the fuel to change water to steam, is only about 70 per cent efficient. This means that for every dollar spent on fuel, 30 cents is wasted, so far as the production of steam is concerned. The way in which the heat is lost will be explained in a later lesson. The higher the temperature of the feed water, the less heat will be required to change it to steam. The exhaust steam, on reaching the condenser, still has quite a bit of heat in it. The condenser circulating water takes enough heat out of the steam to change it back to water and this heat is carried overboard in the discharge of the circulating pump and is a dead loss. If some of the heat is taken from the exhaust steam and used to raise the temperature of the feed water, as is done in the feed heater, it is evident that some of the heat loss is reclaimed and that the boiler efficiency will be increased. Experiments show that if exhaust steam is used to heat the feed water, for every 10° rise in temperature, there is a reduction of 10 per cent in the amount of heat necessary to produce steam. In one type of feed heater, an attempt is made to reduce heat loss up the stack, by utilizing some of this waste heat of the gases of combustion to heat the feed water. Efficiencies of these various heaters vary with the

particular installations, and the savings effected may vary from 1 per cent up to about 20 per cent.

(2) *Prevention of unequal expansion.* It is claimed that there is a distinct advantage in feeding the heated water to the boiler, in that it reduces the strains upon the boiler parts due to extreme temperature differences which cause unequal expansion.

(3) *Increase in boiler capacity.* Due to reduction in time required to change water into steam; moreover, heating surface is more efficient.

(4) *Priming is reduced and quality of steam is better.*

(*b*) *Types.*

(1) *Closed or surface heaters* (Fig. 62). This type is the most common one in marine work. Usually exhaust steam is used, although in certain kinds live steam may be used. The feed water generally passes through the tubes in one direction, whereas the steam passes around the tubes, flowing in the opposite direction. Closed heaters may be classified in accordance with which side of the feed pump they are located on, as

(*a*) *High pressure heater.* In this case it is located in the feed line on the discharge side of the feed pump. Where exhaust steam is used at a pressure of 30 lbs. absolute and temperature corresponding of 250° Fahrenheit, it is possible to bring the feed up to a temperature of 240°. In addition to the use of auxiliary exhaust for these heaters, steam from the receivers of the main engines, especially the low pressure, from evaporator or even live steam may be used.

(b) *Low pressure heater.* This type is located on the suction side of the feed pump. The main advantage obtained is the fact that it is operated at a water pressure of about 18 pounds, while the high pressure heater must be operated at greater than boiler pressure. In this type an additional pump must be used to pump the water from the feed tank through the heater. Moreover. the high pressure heater is more efficient than the low pressure heater because the feed cannot be heated in practice to over 180° Fahrenheit. If heated higher than this, the feed pump is likely to lose its suction, since on the suction stroke; the drop in pressure will cause the hot water to flash into steam which the pump cannot handle.

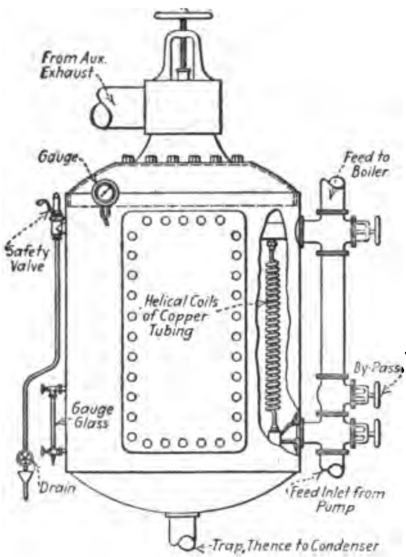


FIG. 62. Feed Water Heater, Closed Type

Closed heaters may also be classified according to their construction as;

(a) *Straight flow heaters.* Similar in construction to the condenser. The steam flow may be opposite in direction to the water flow which is the usual type, or they may both flow in the same direction.

(*b*) *Multi-coil heater*. In this type the feed water flows through a number of coiled copper tubes instead of through straight tubes as in (*a*) type. These have the advantage of allowing, more readily, for expansion and contraction.

(*c*) *Film heater*. This type is similar in principle to the film oil heater described above. The water flows in a film, between an inner and an outer copper tube while the steam flows on both sides of the film. There are a number of these tubes, all of which are corrugated spirally, and enclosed in a cylindrical shell.

(2) *Open or direct contact heaters*. These are also known as *jet injection* heaters. This type of heater may use exhaust steam, either from the auxiliary system, or from any of the sources which the closed heater uses. The steam mixes directly with the water in the feed tank, means being provided to limit the objectionable noise due to this mixing. The condensation of the steam raises the temperature of the water, but the temperature rise is limited to 180°, for the same reason as that which obtains in the case of the closed low pressure heater. This type of heating is not very common in marine practice, but has been used in certain turbine driven ships, where a hot well pump delivered the feed water through the heater whence the feed pump took its suction.

(3) *Economizer*. In this type the feed water is passed through coils of piping so located as to use some of the waste heat of the flue gases. These are generally referred to as "fuel economizers" and are not generally classified

as feed heaters. They are not much used in marine work, being chiefly found in water tube boilers of the Belleville type.

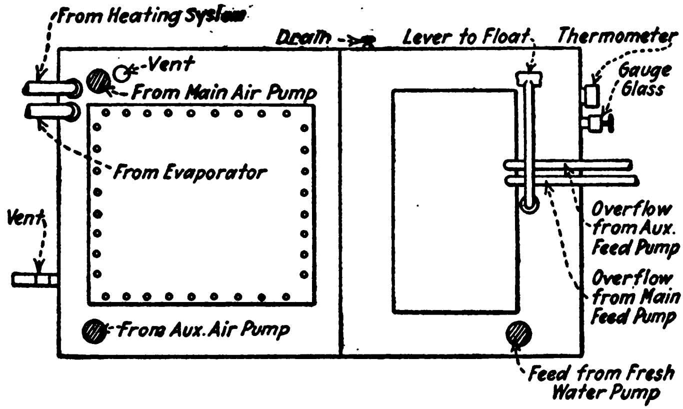
4. Air Remover

After the feed water enters the main feed line, a large air chamber is sometimes installed for the purpose of removing the air. There is an air cock located at the top of the chamber. The air chamber will fill up with water first, and at the end of about 24 hours it will be filled with air which can then be allowed to blow off. Removal of the air tends to reduce corrosion and also to increase boiler efficiency.

5. Hot Well

This is generally a steel tank used for the purpose of holding the feed water coming from the condenser. The term "hot well" cannot be definitely defined. It may refer to a small casting on the side of the air pump or even to the pipe from the condenser, as in the case of small installations, or it may refer to the feed tank which receives all the condensed steam of the system. The *filter tank* (Fig. 63) is usually a part of the feed tank, being simply a compartment located in the upper corner of the feed tank. It is filled with glucose, excelsior, charcoal, loofa sponges or other filtering material. The feed tank is usually fitted with a gauge glass, thermometer, graduated measuring scale, swash plates, drain, vent, and overflow pipe to reserve tanks. Discharge pipes from the main and auxiliary air pumps, from the trap drains, from the fresh water distiller,

and from the heating system lead into the filter tank, while suction pipes from the main and auxiliary feed pumps, and



Plan View of Filter Box

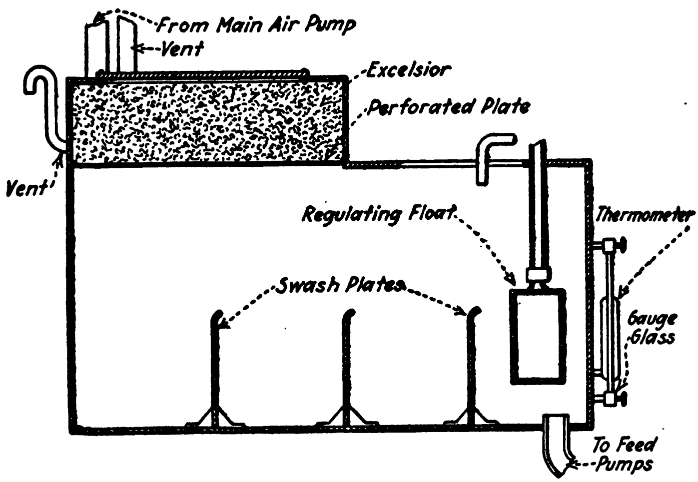


FIG. 63. Feed and Filter Box Showing Fittings

from the injector, are taken from the feed tank. The feed tank is sometimes fitted with a float feed regulator.

6. Reserve Feed Tanks

The space in the double bottoms is usually used for reserve feed tanks. The middle spaces are generally used for this purpose, although in some cases tanks located in the fore and aft double bottoms are also used for feed instead of for ballast (as is usually the practice).

QUESTIONS

1. Give a list of the important tools used by the fireman, together with the function of each.
2. Describe a time firing device.
3. What two general types of ash ejectors are there?
4. Describe the ash hoist.
5. What is the reason for heating oil before using it as fuel?
6. Name three types of heaters.
7. What is the purpose of strainers in a fuel oil installation?
8. Where are the strainers usually located?
9. What is the function of the oil burners?
10. What three types of burners are there?
11. What are the advantages of mechanical burners?
12. What is the purpose of the air register?
13. Name three types of air registers.
14. What are booster pumps used for?
15. What are oil service pumps used for?
16. Name four advantages of feed heating.
17. Describe a closed or surface heater.
18. How are closed heaters classified as to pressure?
19. What are economizers used for?
20. What is an "air remover?"
21. What is the hot well used for and what fittings does it have?

SKETCHES

1. Sketch an oil burner.
2. Sketch an ash hoist.
3. Sketch a closed feed water heater.
4. Sketch a feed and filter box, showing fittings.

LESSON 8 — BOILER CORROSION, ACTION AND PREVENTION

1. What Corrosion is

There are three kinds of corrosion, (1) due to oxidation, (2) due to acid action, (3) due to electrolysis. Corrosion here refers to the deterioration of the metal parts of the boiler. It results either in the metal passing into a fluid, or in changing the state of the metal so that it crumbles easily.

(*a*) *Due to oxidation.* This corrosion involves metallic iron, a certain amount of moisture and some carbon dioxide. The metallic iron combines with the oxygen of the air or with water and forms iron oxide, which is a compound having less strength than iron, and one whose molecules do not stick. This process goes on very slowly but at a continuous rate. Unless all the things mentioned above are present, oxidation will not take place. It is commonly referred to as rusting.

(*b*) *Due to acid action.* Most acids have the faculty of dissolving most metals. An acid plus a metal gives what is called a base. Thus, for example, hydrochloric acid (HCl) plus iron (Fe) will result in iron chloride (FeCl). Or in other words, the hydrochloric acid from the sea water will actually dissolve the iron.

(*c*) *Due to electrolytic action.* Here the presence of two dissimilar metals in an acid or electrolyte results in the

eating away of one of the metals by the small electric current which plates the other metal with the one eaten away. The final results are not differentiated from corrosion by acid action so that the actual amount of electrolytic action is problematical.

2. Where Corrosion May Take Place

Corrosion may take place either on the inside or on the outside of the boiler. That which takes place on the outside is due directly to oxidation. Corrosion may also take place on the fire side of the heating surface. If the furnace is allowed to remain cold, moisture collects in the ash, and acids are often present in the ash. If the proper provision is not made to clean out the ash pits, corrosion due to acid action will take place on the fire surfaces. In the heating surfaces where soot is allowed to collect, moisture will be absorbed and corrosion due to rusting will take place. The inside of the boiler is the part giving the most trouble. In the steam space, corrosion is due to oxidation only, whereas in the water space, corrosion may be due to any of the actions mentioned above.

3. Causes of Boiler Corrosion

(*a*) *Use of sea water.* Certain constituents of the sea water give up acids when heated. Of the salts present in sea water, sodium chloride forms about 78 per cent, while magnesium chloride is present in quantities of about 11 per cent. Other impurities present in sea water, but in very small percentages, are sulphates and carbonates. It must be kept

in mind, that the total percentage of all salts in the sea water is never over 4 per cent. Thus 11 per cent magnesium chloride means 11 per cent of all the salts present and not 11 per cent of the sea water. The magnesium chloride tends to form hydrochloric acid. This eats into the iron, forming FeCl. This in turn acts on the magnesium and then the magnesium goes back to magnesium chloride, thus making the process continuous.

(*b*) *Acid from oils.* The heat of the boiler releases acids from oils, thus starting corrosion. The acid collects in the form of fatty sludges which attach to the boiler. The surfaces become covered with sediment which remains smooth. The use of any but pure mineral oils is unusual today so that corrosion from this cause is not common.

(*c*) *Air in feed water.* This results in oxidation or rusting.

When operating at high vacuums, there is always more or less leakage of air into the pumps. If care is not taken to eliminate or otherwise deal with this air, serious results follow.

(*d*) *Galvanic action.* Consider the boiler as a large wet cell. The shell may then be considered as one electrode and the feed water as the electrolyte. The different parts of the boiler are at different potentials. Hence there is a tendency for an electric current to flow between the parts of different potential. The result is the carrying along of minute particles of the boiler metal by the electrons, which move in the opposite direction to the flow of current. This is called "Electrolysis."

4. Resulting Action on Boilers

(*a*) *General corrosion.* This is the formation of rust scale all over the surface of the material. The action is spread out and very slow. Such action is usually not very serious. It is usually found in Scotch boilers.

(*b*) *Pitting.* This is the most dangerous form of corrosion. It occurs in spots and will be localized within a small area. However, it takes place rapidly and will eat through the shell. Pitt holes are mostly conical in shape, varying from pin holes to diameters the size of the small finger. Immediate steps must be taken to eliminate the cause of pitting and keep it from spreading. It is usually found in fittings or possibly on the tubes. B. & W. boilers sometimes show pitting around the water line inside the steam drum. It is common to find corrosion on both Scotch and water tube boilers where the feed water enters. Corrosion will always be found on that part of the boiler where the circulation is poorest.

(*c*) *Grooving.* Grooving may be due either to oxidation or to acid action. It may also result from unequal stresses in the metal. Thus, for example, if in bending the top of the combustion chamber, too sharp a bend was made, there then results the liability to corrosion due to grooving. Likewise, the injudicious use of the caulking tool may start grooving. With proper care, grooving will not take place.

5. Preventive Measures

(*a*) *Zincs.* Zinc diverts corrosive action from the boiler shell to the zinc itself. In installing the zincs, there must be

a good metallic contact between the zinc and the boiler shell. The zinc should be properly distributed throughout the boiler. The zinc plates will only last for a limited length of time. It is usual to place the zincs in a basket so that they will not fall to the bottom. The zinc oxidizes more readily than iron. Another scheme, which has been tried in this connection, is to introduce an electric current into the boiler, by means of a carbon electrode, insulated from the shell. In a large Scotch boiler 20 volts and from 200 to 300 amperes are necessary.

(*b*) *Use of chemicals.* To prevent corrosion due to acids, we may use either single chemicals or combinations (compounds) of several chemicals. It is usual to put some chemical into the feed water which will change it from an acid to an alkali.

(1) *Sodium carbonate* will serve to neutralize feed water and prevent acid corrosion but it may cause the formation of soapy material which increases the surface tension and then priming results. (Here the bubbles rise out of the surface of the water and may be carried over with the steam to the engine, thus resulting in immediate damage.) To prevent this, only enough sodium carbonate must be added to make the water slightly alkaline. For an ordinary size B. & W. boiler (25 headers) only one to two pounds of soda ash should be added per day for each indicated horsepower of the engine.

(2) *Lime* will not produce foaming, but it increases the liability to scale formation, thus resulting in overheating of some of the heating surfaces.

(3) *Boiler compounds* are composed of several different substances. A boiler compound should accomplish the same results as the individual chemicals. It must not only prevent corrosion, but also scale formation, foaming and priming. It would be ideal to get rid of the zincs by another chemical. Calcium sulphate (CaSo) has been suggested for this purpose, but as yet its efficacy is more or less theoretical.

A compound used with success in the U. S. Navy consists of: Na_2CO_3 95 per cent (sodium carbonate) to make feed alkaline, $NaHPO_4$ 4 per cent (sodium hypophosphate) to prevent foaming, Cutch 1 per cent (made from tannic acid bark) to prevent scale.

(*c*) Use of *pure mineral oils* is a preventive measure.

(*d*) *Elimination of air*. This is also a highly important preventive measure. Air should be excluded from the entire system. All connections should be air-tight, and feed connection should be kept tight. In the water tube boiler the feed should enter through the steam drum.

Note. — Zincs should never be used in the same boiler with compounds. The amount of compound necessary will depend upon type of boiler, size and other conditions. The use of too much compound may increase corrosion.

6. Methods of Testing Water — Apparatus Used

(*a*) *Acidity*. Use an indicator such as litmus paper. If the paper turns red the solution is acid, while if it turns blue the water is alkaline.

(*b*) *Alkaline test*. Feed should be kept between neutral and ½ of 1 per cent alkaline. Pitting will result if over ½

of 1 per cent alkaline. To make a quantitative test, add nitric acid to the sample and calculate from the amount of acid necessary to neutralize the sample the percentage of alkalinity.

(c) *Chlorine test.* Not more than a certain amount of chlorine should be allowed per gallon of feed water. One hundred grains per gallon is safe for the B. & W. boiler, whereas 30 is the limit for express boilers. To make the test a certain amount of the sample is first neutralized or made slightly alkaline by the use of about a drop of sodium carbonate. This turns sample yellow. A known amount of silver nitrate is added until sample turns reddish.

QUESTIONS

1. Define "Corrosion."
2. Where may corrosion take place?
3. Name four causes of corrosion.
4. Explain what is meant by general corrosion, pitting and grooving.
5. How does zinc act to prevent corrosion?
6. What chemicals are used to prevent corrosion?
7. How is water tested for acidity?
8. How is water tested for alkalinity?
9. How is water tested for chlorine?

LESSON 9 — DRAFT AND DRAFT EQUIPMENT

1. Draft and Draft Systems

(*a*) *Use.* To furnish oxygen to burn the fuel. The draft produces a flow of gases. Cold air passes through the furnace, is used in burning the fuel, and the heated gases and air expand and rise in the funnel. By increasing the draft, the rate of combustion can be increased.

(*b*) *Measurement.* The amount of draft, or in other words, the difference in pressure causing the draft, is usually measured in inches of water. The weight of 1 cubic foot of water at 62° Fahrenheit equals 62.3 pounds.

Hence 1″ of water will exert a pressure

$$= \frac{62.3}{12} = 5.19 \text{ pounds per square foot.}$$

The most important place to measure the draft is just below the grate. Apparatus used for this will be described later.

(*c*) *Methods of producing draft:*

(1) *Natural draft:*

(*a*) *Theory.* The weight of the column of gases in the funnel is much less than an equal volume of air outside. This gives a difference of pressure, which results in the cooler air coming in under the grate, and the hot gases rising up the funnel.

(*b*) *Limitations.* The height of the funnel limits the

amount of draft. The funnel height will vary between 80 and 100 feet above the grate surface. This will result in a draft of from 0.5 to 0.7″, which will give an approximate rate of combustion of from 14 to 20 pounds of coal per square foot of grate surface.

(*c*) *Application.* Natural draft is used on the majority of coal burning merchant ships. On these ships there is no demand for great increase of the rate of combustion or for unusual speeds. Of course, the amount of steam which the boilers can furnish is limited to a certain amount only, but this does not constitute a great disadvantage for a merchant ship.

(2) *Mechanical draft:*

(*a*) *Why used.* Mechanical draft provides an artificial means of increasing the draft and hence the rate of consumption without necessitating an increase in funnel height. By thus forcing the boilers, it is possible to obtain greater power for a given weight and on a given floor area, without increasing the funnel temperature. Forced draft is a necessity in most oil burning installations, in ships having low funnels, such as destroyers, and in general in all modern battleships, where the supply of air would be insufficient with the use of natural draft.

(*b*) *Systems of mechanical draft:*

(1) *Closed fire-room.* The closed fire-room is, in general, found mainly in naval vessels. In this system, everything is made air-tight from the protective deck down. Blowers force the air into the fire-room

and the only way out is through the furnaces. In this system the smoke stack is generally double, with an air space of 3″ between. There are two ways to get out of fire-room, one up a ladder and out through an air lock, and the other through an air lock to the engine room. The watch usually come up and down through the engine room. This system is the least economical of any forced draft system, is expensive to install, and is hard on the firemen. It is not in use in the merchant service, but finds its application chiefly on war ships where it can readily be installed.

(2) *Closed ash pit.* This is an open fire-room system where centrifugal blowers are used to force the air through air passages into the ash pits and up through the furnaces, these being made air-tight. This system is efficient and simple and well adapted to merchant service.

The *Howden system* (Fig. 64) is a special adaptation of the closed ash pit system. It is more generally used than any other type. In this system the air to be used for combustion is heated before it reaches the furnace, by passing it around a nest of thin tubes which are placed in the uptake, and through which the hot gases of combustion pass. The supply of air is automatically shut off when the furnace door is opened, thus preventing the hot air from getting out into the fire-room. This system is very economical and is used, almost to the exclusion of all others, in the merchant marine. It is necessary to carry a thicker fire with the Howden system. It has an additional advantage, that wood from boxes, etc. (when

vessel receives stores), can be used for fuel. These could not be used in the closed fire-room system. The Howden

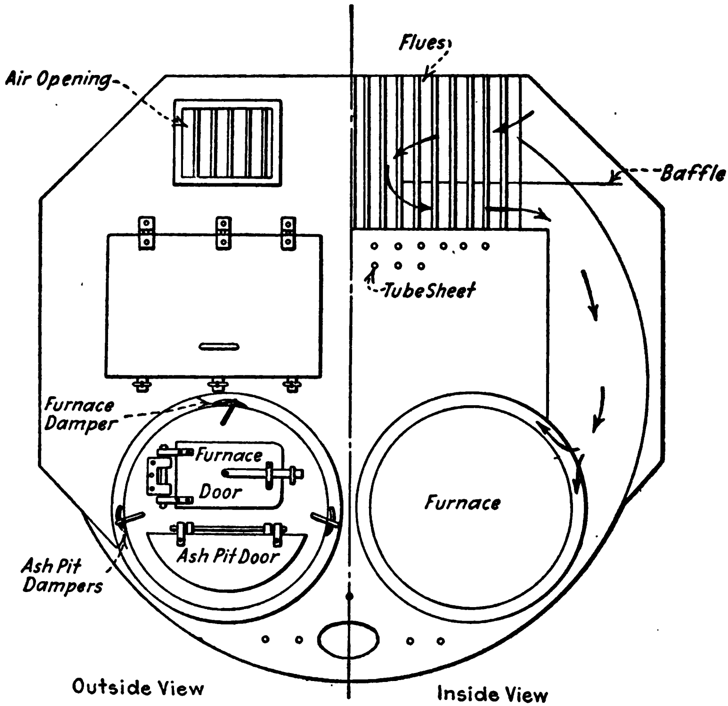


FIG. 64. Sketch Showing Two Furnace Scotch Boiler Equipped with Howdens Forced Draft

system may be used on either fire tube or water tube boilers.

(3) *Induced draft.* This system is an open fire-room system in which the draft fans are located in the base of the funnel, or sometimes in the uptake of each boiler. About

10 per cent more power is required to run the fans than in the Howden system. There is some economy of fuel, but the main advantage lies in the fact that it is an open fire-room system. This system is not much used in this country but has been installed on some British ships.

The *Ellis* and *Eaves* system is a special form of the induced draft system. In this system, means are provided for heating the air, before it is drawn into the furnace by means of the waste gases, as in the Howden system. The air is drawn into the furnace both above and below the fire grate. The hot gases pass through the combustion chamber and tubes to the smoke box and are then made to pass around a number of thin tubes above the boiler, finally passing through the fan to the funnel. The air supply passes inside of these thin tubes before being drawn to the furnace.

The steam blast is another type of induced draft system. Here the steam is introduced into the base of the funnel in jets, reducing the pressure there and thus producing an induced draft. This system is wasteful of steam and water and is not much used in marine work, except in small vessels.

The exhaust blast uses exhaust steam from a non-condensing engine instead of live steam. This method also results in a loss of fresh water. It is only used on small vessels such as tugs.

(4) Other methods for increasing rate of combustion are the use of jets of compressed air blown into the furnace and also the use of jets of liquid fuel blown over the hot

coals. Both of these methods, while not very commonly used, will increase the combustion rate. The use of the air under pressure and its method of introduction may result in a much better mixing and combustion.

2. Fans and Blowers

(*a*) *Types*.

(1) *Disc or propeller fan.* In this type the air moves through the fan practically parallel to the shaft and perpendicular to the plane of rotation of the wheel. Disc fans may be classified as:

(*a*) Straight blade fans.

(*b*) Curved blade fans.

The disc type of fan is mainly used for large volumes at low pressures. It is not as efficient as the ordinary centrifugal blower.

(2) *Centrifugal blower or peripheral discharge fan.* In this type the air enters the fan wheel at right angles near the center, and is deflected through a right angle as it goes through the wheel and leaves the periphery of the wheel at a high speed owing to the centrifugal force given to it. These fans may be classified as:

(*a*) *Fans without diffusers.* These fans have a casing which is concentric with the fan. They may have either straight or curved blades. The curved blade gives a smoother and less noisy action and is more efficient.

(*b*) *Fans with diffuser.* In this type the casing forms a gradually increasing spiral, giving more and more

space between the wheel and the casing until the outlet is reached. This construction serves the purpose of changing some of the velocity head of the air to pressure head and hence this type is especially adapted to forced draft blowers. These blowers are made with both straight and curved blades. The straight blade fan is very commonly used for forced draft.

(c) *Sirocco blower.* This is a special type of centrifugal blower, having a large number of long narrow blades, curved forward in the direction of rotation and mounted parallel to the shaft. This type of blower is very efficient.

(b) *Location:*

(1) *Fire-room level.* The blower is very often placed here in the Howden system.

(2) *Top of boiler.* In the Ellis and Eaves system the blower is often placed on top of the boilers.

(3) *Suspended from the protective deck but in the fire-room.* As in older U. S. vessels.

(4) *In special blower compartments*, as in later type U. S. ships, these compartments being above the fire-room.

(c) *Balancing.* It is necessary, in installing a blower, that it be properly balanced and aligned, as otherwise, noise and vibration will result. Vibration may also result from too high a speed and supports which are too light.

(d) *Air ducts.* These must be kept air-tight at all times. Dampers are fitted, being placed in the ducts for the purpose of shutting off the air when the furnace doors are opened; they are also used in some systems of forced draft, to by-

pass the fan, so that natural draft may be used in an emergency.

3. Fan and Blower Drives

(*a*) *Types.*

(1) *Reciprocating engine.* The engine may be of the single cylinder type or a two cylinder engine may be used. Forced lubrication is generally provided for the bearings.

(2) *Electric motor.* The speed regulation of electric blowers is simple and the control is convenient. Electric blowers are not used for oil fuel installations.

(3) *Turbine.* These drives are very reliable and easy to control. In some types the blower is vertical, while in others it is horizontal.

(*b*) *Proportions.*

(1) *Number.* Two blowers are usually fitted for each boiler room. Thus, if one breaks down, the other one is available.

(2) *Speed.* Different speeds are necessary in order to obtain different air pressures. It is possible to get 10 different speeds out of a Sirroco blower. In this type a speed of 900 R.P.M. will give about 2″ and the speed may be varied from 900 to 1400 R.P.M. The reciprocating engines vary in speed from 300 to 750 R.P.M.; the electrically driven blowers between 750 and 1400; and the turbo-blowers from 900 to 1600 R.P.M.

(3) *Efficiency.* The efficiency of a fan or centrifugal blower is:

$$\text{Eff.} = \frac{\text{Developed Horse Power based on average air discharge}}{\text{Applied Horse Power (input) received by the fan}}$$

In a test of a Sturtevant Blower (No. 5), the highest efficiency obtained was about 60 per cent and this was reached at a speed of 1141 R.P.M. The efficiency (maximum) dropped down to 57 per cent at a speed of 1625 R.P.M. The static head was found to increase directly as the square of the speed, while the developed horsepower, based on average air discharge increased directly as the speed. The horsepower required by the blower, increased approximately as the cube of the speed.

(*c*) *Fittings:*

(1) *Reducing valves.* These are always used to give steady steam pressure.

(2) *Steam gauges.* These are placed between the reducing valve and the engine.

(3) *Air pressure gauges.* These gauges are often made in the form of a U-tube containing water. One end is placed where the draft measurement is desired and the other end is open to the atmosphere. Another type of gauge, the Ellison draft gauge, replaces the lower part of the "U" with a tube which is slightly inclined to the horizontal. The effect of this is to increase the sensitivity of the gauge. Oil is used in this gauge instead of water.

(4) *Oil systems.* Both forced lubrication systems and automatic sight-feed oiling systems are in use. Care should be taken that the proper amount of oil is supplied.

(5) *Tachometers.* These are used to determine the exact speed in revolutions per minute. They depend for operation upon the centrifugal force, which throws weights in the instrument outward, this motion being communicated

by levers to a needle. The outward force is proportional to the speed and the scale over which the needle moves is calibrated directly in R.P.M.

QUESTIONS

1. Why is draft necessary?
2. How is draft measured?
3. Where is the most important place to measure draft?
4. What is the theory upon which the production of natural draft is based?
5. What are the limitations of natural draft?
6. What are the applications of natural draft?
7. Why is mechanical draft used?
8. What is meant by the closed fire room system of mechanical draft?
9. Describe a type of closed ash pit system.
10. Describe the Ellis & Eaves induced draft system.
11. How are disc fans classified?
12. Name three types of centrifugal blowers and explain in what respect they differ.
13. Where are the fans or blowers located?
14. Why are the blowers balanced when installed?
15. What three types of drives are used for fans and blowers?
16. What is the usual speed and efficiency of a fan or blower?
17. Describe the various blower fittings.

SKETCHES

1. Sketch a two furnace Scotch boiler equipped with Howdens forced draft.

LESSON 10 — BUNKERS AND FUEL OIL TANKS

1. Coal Bunkers

(*a*) *Location.* In merchant ships, bunkers are usually fore and aft of the fire-rooms. They are usually on two levels known as the upper and the lower coal holes. They have a capacity of 700 or 800 tons. There are from 24 to 36 bunkers in a first class battleship. These average 80 tons capacity each. Gunboats have from 2 to 6 bunkers.

(*b*) *Fittings.* The following fittings are sometimes found in bunkers:

(1) *Water-tight doors* between the upper level and the lower level chutes. On battleships, these doors can be opened or closed from a distance (long arm system) and howlers are fitted to give warning when the door is to be operated.

(2) *Chutes and doors to upper bunkers.* Chutes for filling the lower bunkers are placed nearly directly over the doors leading to the fire-room. Doors are provided in upper bunkers, so that coal can be trimmed from them into the lower bunkers. Chutes are sometimes provided leading directly to the fire-room. Doors opening into the fire-room are always vertical sliding doors.

(3) *Ventilators.* Ventilating pipes are fitted, leading from the highest point in the bunker to the atmosphere.

(4) *Lighting.* Electric lights are fitted in the bunkers and

no open light should be permitted in a bunker or near the opening of a bunker unless that bunker has been well ventilated.

(5) *Fire extinguishers.* These consist of jets of steam which can be turned on the coal in case of fire.

(6) *Thermometers and fire alarms.* Thermometers and thermostats are provided. The latter automatically turn in an alarm and indicate the location of the bunker, when the temperature in the bunker reaches a certain predetermined limit. If thermometers are not provided, a method of getting the temperature of the bunker is to drill perforations into a 2″ pipe, put a thermometer into this and lower into the bunker. Spontaneous combustion starts in a bunker directly in the center of the coal pile. It occurs principally in the inboard bunkers. Flooding bunkers is practiced on some ships if a fire occurs. It is customary in fine weather to remove bunker plates and air bunkers.

(*c*) *Calculations.*

(1) *Calibration of bunkers.* Calibration marks are generally put at the right of the ladder or grab iron. They are put on with a center punch.

(2) *Estimates — when made.* Estimates of the amount of coal should be made each day when steaming. A coal book should be provided with a page for each bunker. Headings should be as follows:

Bunker Number	Date of last Coaling	Amount in Tons
10	Dec. 18, 1918	800
	Estimate — Dec. 19, 1918	760
	Dec. 20, 1918	720

(3) *Method of estimating.* In estimating the amount of coal, the volume accepted as standard is 43 cubic feet to the ton. The total volume of the bunker divided by 43 is taken as the amount of coal when the bunker is full. As the bunker is emptied, the volume not occupied by coal is measured by means of a tape and this divided by 43 gives the amount of coal used up. This is subtracted from the last estimate.

(*d*) *Re-fueling.*

(1) *Systems.*

(*a*) *Deck chutes.* Used on naval vessels.

(*b*) *Side chutes.* Used principally on passenger ships.

(*c*) *Cargo hatch.* Used on merchant ships.

(2) *Gear used.* Merchant ships are provided with winches for handling either cargo or coal. Booms are attached to masts and the winches swing the booms to the desired position and lower and raise the buckets by means of wire rope rigging. It is usual to have one winch for swinging and one for hoisting, although winches are made which will perform both these operations by means of suitable shifting gears. A clam shell bucket is commonly used to pick up the coal from the barge alongside. Sometimes ordinary buckets are used which must be filled by hand. A new device has been placed on the market for coaling ships through side chutes. It is a self-contained coal digging unit which is hung on the side of the ship to be coaled. The machine can be put up or taken down in five minutes time. An electrically operated lifting boom picks up the coal, with a standard clam shell bucket which

automatically swings in over a hopper to its dumping position when full. It is claimed that one operator can handle more coal with this device than fourteen men with the ordinary gear.

(3) *Tallying and weighing.* It is customary to check each bucket or bag as it comes aboard from the barge or collier. The best tally is the bunker itself. A box of known dimensions may be used for measuring the density of the coal — usually a half to a quarter ton box.

(4) *Stowing.* Men should be stationed in the bunkers to trim the coal away from the chute as the coal is poured in. The bunkers should be filled right up to the lower edge of the deck beams. When no more coal can be stowed in the bunker, the last trimmer leaves the bunker through the chute and the chute is filled with coal. Coal should not be stowed moist.

2. Fuel Oil Tanks

(*a*) *Location.* In oil burning ships, the bottoms under the fire-room are used for fresh water, while those under the engine room are used for fuel oil. Sometimes all the double bottoms are utilized for fuel oil tanks, except those under boiler and engine rooms, which are used for feed.

(*b*) *Kinds of tanks.*[1]

(1) *Storage tanks.*[1] A riveted tank must be used for oil. There should be an air space between an oil storage tank and the fire-room.

(2) *Settling tanks.*[1] The oil for immediate use is taken

[1] NOTE. — See lesson on Fire Room Accessories — Oil Burning; par. 2 (*g*) and (*h*).

from the settling tank. It often performs the function of a measuring tank and is fitted with a steam coil for heating the oil to the proper viscosity and for getting rid of the moisture.

(*c*) *Tank fittings.*

(1) *Manholes, hatches.* Manhole plates are put on all oil tanks. Rubber gaskets are not satisfactory, as they will not stand the oil. Most fittings use paper at the joints. The manhole hatches or covers leading to the double bottoms have flat braid of flax or hemp laid in the grooves.

(2) *Sounding tubes.* All tanks have sounding tubes. These are not very reliable, especially when the ship is rolling.

(3) *Oil suction and discharge, sluice valves, and water suctions.* This latter fitting is a salt water connection used for expelling gas and for cleaning.

(4) *Fire extinguishers.* Steam connections which are also used for steaming out the tank.

(5) *Pneumercator.* A patented pneumatic device which indicates, at any convenient place, the amount of oil in the tank, by means of the height of a calibrated column of mercury. A balance chamber is located near the bottom of the tank and from there a small air pipe leads to the calibrated gauge, fitted with a control valve, and to an air pump. An annunciator is also fitted to this device to indicate when a tank is at "low level" and when it is 95 per cent full.

(6) *Heating coils.* These are fitted at the bottom of storage tanks to reduce the viscosity of the oil. They are also sometimes fitted near the surface of the oil in

the settling tank to send the lighter oil to the top and the denser water to the bottom, where it can be drained off.

(*d*) ***Fuel oil system.***

(1) *Piping.* Fuel oil piping should be run above the floor plates wherever feasible, and when run under the floor plates, care should be taken to make it easily accessible. Oil fuel suction pipes are usually of lap welded steel while the service pipes are of seamless drawn steel. A filling line is usually run from the port to the starboard side and hose connections are fitted at the sides. A pipe is run from this line to the suction manifolds and thence to the storage tanks.

(2) *Course of oil.* Storage tank through suction line to booster pump, to settling tank, through strainers, meter, heaters, and service pump to burners.

(*e*) *Calculations.*

(1) *Calibration of tanks.* One ton of oil occupies 39 cubic feet. Hence if the volume of the tank in cubic feet is divided by 39, the capacity in tons will be obtained. To obtain the capacity of the tank in gallons multiply the cubic feet in the tank by 6.3.

(2) *Soundings.* Soundings should be taken daily when steaming. If pneumercators are fitted, the soundings should check with the pneumercator readings.

(*f*) *Re-fueling.*

(1) *Gear used.*

(*a*) *Hose into tank.* This method is seldom used.

(*b*) *Hose into flange connections.* The hose is usually a fitting belonging to the tanker.

(2) *Men necessary.* It is a three man job to re-fuel with oil.

(*a*) Rigging and unrigging.

(*b*) Pumping.

(*c*) Standing by tanks and valves.

(3) *Operation.*

(*a*) *Soundings.* Each tank should be sounded daily.

(*b*) *Trimming.* Although the oil can be used in emergencies for trimming the ship, it is poor practice to transfer it from one tank to another for this purpose.

(*c*) *Precautions.* An oil tank should never be filled over 95 per cent of its capacity.

(*g*) *Comparison between bunker capacity and oil tank capacity.*

(1) Space is available for oil, which cannot be utilized for coal.

(2) A ton of coal takes up 43 cubic feet, while a ton of oil only requires 39 cubic feet.

(3) Steaming radius of ship increases with use of oil fuel. The *economical speed* of a ship is that speed at which it will make a nautical knot with the least expenditure of fuel. Hence the steaming radius is determined by dividing the amount of fuel carried by the amount consumed when the ship is going at the economical speed. In addition to the advantage of occupying less space, the oil has more heat units per pound than the coal and burns more efficiently and hence the steaming radius of the ship using oil fuel may be more than 33 per cent greater than a sister ship using coal.

QUESTIONS

1. Where are coal bunkers usually located?
2. Name the various fittings sometimes found in coal bunkers.
3. When should estimates of coal be made?
4. Explain the method of estimating the amount of coal.
5. Name three systems of re-fueling and tell where each is used.
6. What gear is used for re-fueling?
7. What is the usual method of tallying and weighing?
8. How should the coal be stowed?
9. Where are the fuel oil tanks located?
10. Name the various tank fittings and their uses.
11. How are the tanks calibrated?
12. When should soundings be taken?
13. What gear is used in re-fueling with oil?
14. How many men are necessary in re-fueling?
15. What special precaution must always be observed in filling an oil tank?
16. Compare bunker capacity and oil tank capacity, with reference to space available, and relative space occupied by coal and oil.
17. What is meant by the "economical speed" of a ship?
18. What is the "steaming radius" of a ship?
19. Why does the use of oil fuel increase the steaming radius of a ship?

LESSON 11 — REGULATING AND PROTECTIVE DEVICES

1. Traps

(*a*) *Function.*

(1) Clear lines of water.

(2) *Water seal.* Water in the trap acts as a seal to prevent loss of steam. With a low water level, the trap is automatically closed.

(*b*) *Types.*

(1) *Float type.*

(*a*) *Bucket type.* This type will take care of a sudden

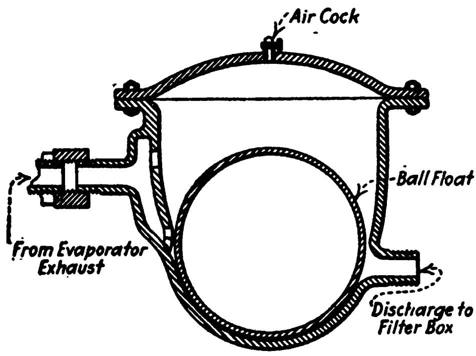


FIG. 65. Cross-Section of Trap Used with Evaporator-Ball Float Type

rush of water and will handle water of varying temperature without adjustment. The Lytton trap is an example of this type. The bucket, when full, opens the valve.

(*b*) *Ball float type* (Fig. 65). This type is simple in

operation and requires little attention. The Johns Manville is an example. The water in the trap, as it rises, lifts the ball float and when a certain level is reached, the float, through levers, opens a valve and the trap discharges.

(2) *Expansion type.* This trap requires adjustment for varying temperatures of water. The opening and closing of the valve is accomplished by means of the expansion and contraction of a metallic element which is in contact with steam when the trap is empty and water as the trap fills.

Traps on high pressure lines are called high pressure traps and those on low pressure lines are called low pressure traps. Traps should be adjusted to operate at definite pressures.

(*c*) *Care and upkeep.* Traps should be inspected at regular intervals. If the float traps are not heard to discharge they should be examined to determine the cause of the trouble. An expansion trap should be tested frequently by opening the by-pass to the bilge. A steam leak can be discovered thus and this also gives a means of determining whether it is operating correctly.

(*d*) *How installed.* A trap should be installed below the lowest part of the line to be drained. Wherever possible it should be put higher than the tank into which it drains. Traps should be easily accessible for inspection and repairs. Wherever possible drains from traps should run to feed tank. It is better practice to install a large trap than several small ones. No trap should be installed unless it is

absolutely necessary. If there is a large and uniform amount of water draining from certain apparatus, a drain collector or tank acting as a water seal will be preferable to a trap. Feed heaters and evaporators are often operated with simply a water seal instead of a trap. Where there is a discharge by-pass fitted to a trap, this should be frequently operated.

2. Reducing Valves

(*a*) *Function.* To furnish a lower constant pressure to any machinery than the pressure of the main steam line. The term "steam pressure regulator" is more fitting.

(*b*) *Principle of operation.* The pressure is reduced by wire-drawing or throttling the steam. The position of the valve is regulated by means of a small amount of the incoming steam by-passed through a pilot or regulating valve to one side of a diaphragm. Springs oppose the movement of the diaphragm, and movement of the diaphragm regulates the opening of the main valve.

(*c*) *Types.*

- (1) *External spring.* Foster reducing valve is typical of this type.
- (2) *Internal spring.* Various makes:
  - (*a*) Leslie.
  - (*b*) Lytton.
  - (*c*) Mason.

(*d*) *Setting.*

In general, most of these reducing valves are set for the desired pressure by regulating the tension of the adjusting spring. In the Foster regulator, the movement of the valve

is controlled by the diaphragm, which is balanced on one side by the incoming steam and on the other by the springs which tend to keep the valve open. An increase of steam pressure tends to close the valve, while a decrease allows the valve to open wider.

In the Leslie valve, the movement of the diaphragm affects a controlling valve and not the main valve directly. The main valve is held against its seat by a spring which is placed at its lower end. At the upper end of the valve stem there is a piston fitted into a cylinder. The amount of steam acting on the top of this piston is determined by the position of the control valve and this in turn is regulated by the amount of the reduced pressure on one side of a small diaphragm and by the action of a spring on the other side. The operation of the Lytton valve is very similar to that of the Leslie.

3. Pump Governors

(*a*) *Function.* To automatically maintain a desired pressure on the discharge side of a pump. These governors are usually fitted to feed pumps.

(*b*) *Principle of operation.* The amount of steam to the steam end of the pump is controlled by a balanced valve. The amount which this valve opens depends upon the discharge water pressure.

(*c*) *Types.*

(1) *Automatic regulating throttle valve.* In this type the opening of the throttle valve can be controlled by a handwheel and is also automatically regulated by means of a piston fastened to the upper part of the valve stem.

The steam acts on the under side of this piston and water from the discharge of the pump acts on the upper side. If the water pressure tends to fall, the piston is raised by the steam, and this opens the valve still more, thus giving the pump more steam and speeding it up. The area of the under side (steam side) of the piston is made greater than that of the water side in order that the water pressure will always be maintained at a certain percentage above that of the steam.

(2) *Ideal pump governor.* In this governor, the opening of the throttle valve is regulated by balancing the discharge water pressure against the action of a spring. Two springs are provided for fine and for large adjustments. This type has the advantage of close adjustment, better wear, and more convenient operation than type (1).

(*d*) *Operation.* The Ideal governor gives better service than the automatic, since in the latter type there is a possibility of steam leakage and the piston may stick, due to wear.

4. Separators

(*a*) *Function.*

(1) To separate and remove the water from the steam.

(2) To increase the quality of the steam so as to supply the driest steam possible to the engines.

(*b*) *Where located.* In the engine room, on the main steam line, near the engine throttle valve.

(*c*) *Principle of operation.* In some types the steam is given a sharp change in direction and this serves to separate the water from it, since the heavier water cannot keep up

with the lighter steam. In another type, the steam is given a whirling motion and the water is separated due to centrifugal force. The Stratton separator is of this type.

(*d*) *Fittings.* Separators are fitted with a gauge glass and a drain leads from the bottom of the separator to an automatic trap.

5. Expansion Joints

(*a*) *Function.* To allow for expansion and contraction taking place in steam and feed piping as the temperature changes.

(*b*) *Types.* The type of expansion joint depends upon the size of the pipe and the space in which it is installed. The following are some of the types in use:

(1) *Packed slip joint.* In this type a sliding pipe is clamped tight to one end of the pipe by means of studs passing through flanges. These studs also screw into a flange on a stuffing box casting. The stuffing box is fastened to the other end of the pipe by means of bolts passing through flanges. A gland fits in between the sliding pipe and the stuffing box and the tightness of the packing can be adjusted by studs which pass from the gland to the flange of the stuffing box. This construction allows the sliding pipe to move in the stuffing box whenever there is any contraction or expansion of the steam main to which it is rigidly attached.

(2) *Expansion loop.* This merely consists of a U-shaped pipe fitted in the center of a straight run of piping. It is very commonly used and its simplicity is an advantage.

(3) *Fittings joint.* This consists of an expansion loop

made up of pipe fittings, such as elbows, etc. It is not in great favor.

(4) *Corrugated expansion joint.* Here the pipe is corrugated and the corrugations take care of the expansion. This type is found in copper feed pipes.

(5) *Globe joint.* Here a rather large globe-shaped fitting is put in to take care of the increase and decrease of length. This type is not used very extensively

6. Strainers

(*a*) *Function.* Steam strainers are used to prevent foreign matter being carried along with the steam to the high speed turbine.

(*b*) *Description.* These strainers are of gauze wire and are generally fitted on the turbine just ahead of the maneuvering valve. They should be cleaned every three or four months. A clogged strainer will result in greatly reducing the steam pressure at the turbine, and this will reduce the efficiency.

(*c*) *Other kinds of strainers.* Strainers are also fitted in the following places and will be described under other headings:

(1) At the end of bilge piping and near bilge pump suction.
(2) In oil fuel systems.
(3) In forced lubrication systems.
(4) On overboard valves.
(5) On suction side of some centrifugal pumps.

7. Packing

(*a*) *Steam gland packing.* Fitted in stuffing box, around piston rod, valve stem, and expansion joint. Metallic pack-

ing is commonly used on main engines, whi.e fibrous packing is generally found on auxiliaries.

(1) *Metallic packing.* The principle on which the use of metallic packing is based is that two smooth or ground metallic surfaces will make a steam tight joint. The packing is made of soft metal, since when this wears, it can easily be renewed. The following are the names of some of the more common metallic packings:

United States metallic packing.

Lee-Cook metallic packing.

France metallic packing.

Katzenstein metallic packing.

(2) *High pressure packing.* In all fibrous packing, asbestos must be used as a constituent in all cases where steam is involved. The higher the pressure, the more asbestos must be used. The objection to asbestos is that it has a tendency to get hard under high temperature and it then can cut the hardest steel.

(3) *Low pressure packing.* If asbestos is used, it must be softer than that used for high pressures. Canvas packing consisting of a rubber core (to give elasticity) surrounded by canvas (Tuck's) is often used for low pressures.

(*b*) *Water gland packing.* Asbestos is never used for water. Rubber compounds are often used. Where the water is under high pressure and at a high temperature, special care is required. One packing which gives good service is composed of excelsior, paper, canvas and a small percentage of rubber. The percentage of rubber allowable is greater for low temperatures. For low pressures, either canvas packing,

such as Tuck's, is used or else square braided flax. The flax has the advantage that it does not swell when wet.

(*c*) *Plunger packing.* Metal rings made in two sections are often used. They are constructed so that the metal bearing against the plunger is a soft metal such as white metal, while the outside of the ring is brass or composition. Lignum-vitae, ebonite, and vegetable compounds are also used for plunger packings. For low pressure and cold water, flax packing is used.

(*d*) *Sheet packing.* This type of packing is used between flat surfaces. High pressures necessitate a material strong enough to withstand high temperatures. The packing should be made as thin as possible. The sheet packing when cut out to fit the joint is ca'led a *gasket.* Asbestos is used for steam. Steam packing is generally impregnated with graphite which acts as a lubricant. Asbestos cannot be used alone for water, but must have rubber in compound with it.

QUESTIONS

1. What are the reasons for using traps?
2. Name the various types of traps.
3. What are the advantages of each?
4. What is the function of reducing valves?
5. Name several types of reducing valves.
6. Describe the principle of operation of one type of reducing valve.
7. What are pump governors used for?
8. Name and describe two types of pump governors.
9. What two purposes do separators serve?
10. What is the principle of operation of the separator?

11. Where are separators usually located?
12. Describe one type of separator.
13. Why and where are expansion joints used?
14. Name five different types of expansion joints.
15. Describe the packed slip joint.
16. What is the function of strainers?
17. Name the various uses to which they are put.
18. What are the various kinds of steam gland packing?
19. Describe water gland packings.
20. Is there any difference in packing used for hot water and that used for cold?
21. What is sheet packing used for?
22. Describe a packing for oil pump plungers.

SKETCHES

1. Sketch the cross section of a ball float trap.

LESSON 12 — FUELS

1. Kinds of Coal

(*a*) Anthracite.
(*b*) Semi-anthracite.
(*c*) Semi-bituminous.
(*d*) Bituminous.

2.* Classification of Coals according to a Proximate Analysis

Classification	Per cent fixed C	Per cent volatile matter	Heating value per lb. of combustible (B.T.U.)	Relative value of combustible. That of semi-bituminous-100
Anthracite..........	97.0–92.5	3.0– 7.5	14,600–14,800	93
Semi-anthracite......	92.5–87.5	7.5–12.5	14,700–15,500	96
Semi-bituminous.....	87.5–75.0	12.5–25.0	15,500–16,000	100
Bituminous, Eastern..	75.0–60.0	25.0–40.0	14,800–15,500	96
Bituminous, Western.	65.0–50.0	35.0–50.0	13,500–14,800	90
Lignite..............	Under 50	Over 50	11,000–13,500	77

3. Characteristics of Each Kind of Coal

(*a*) Anthracite — appearance is lustrous black — structure is same throughout — ignition is rather difficult. This coal does not coke. Its flame is practically smokeless.

(*b*) Semi-anthracite — appearance black — not as hard nor

* Taken from "Marine and Naval Boilers" by Lyon and Hinds.

as solid as anthracite but harder and more compact than semi-bituminous.

(*c*) Semi-bituminous — appearance black — comparatively soft, but harder than bituminous coal — structure uniform — low in oxygen, moisture, ash, and sulphur — volatiles average about 20 per cent of combustible matter. This coal is considered as the best steaming coal obtainable.

(*d*) Bituminous — appearance dull black — will leave a stain on hand, whereas anthracite will not. It has the property of absorbing moisture from the air. It may be classified as *coking* or *non-coking*. A coking coal is one which softens when heated, the parts forming a solid coke. This does not happen with a non-coking coal, the parts remaining separated. A high percentage of volatile matter will result in a *long flaming* coal while a lower percentage will give the *short flaming* coal.

Other kinds of coal, such as lignites, cannel coal, etc., are not of importance for marine work.

4. General Properties of Coals

(*a*) *Coking qualities of coal.* Coking is not objectionable provided the bed is broken up at proper intervals.

(*b*) *Tendency to clinker.* The heat may be sufficient, with certain coals, to fuse the ash. This means the formation of undesirable clinkers. Steam, if passed through the fire, may reduce the formation of clinkers. Water in the ash pit has been used to accomplish similar results. The breaking up of the steam into hydrogen and oxygen takes heat from the ash. Mixtures of coals, which would not clinker when

used separately, may clinker due to the freeing of chemicals in one coal capable of fusing ash in the other. Sea water increases clinkering.

(*c*) *Bad effects of sulphur.* Sulphur has an injurious effect on the boiler and it is usually accompanied by clinker forming chemicals. Sulphur should not be present in excess of three to four per cent.

(*d*) *Color of ash.* A reddish color means the presence of iron oxide, while a yellowish color shows the presence of iron pyrites. It is also possible to tell from the color of the ash whether or not the combustion has been complete.

(*e*) *Weathering of coal.* The effects of weathering on coals result not only from moisture and heat conditions, but also from the quality of the coal, particularly with reference to the percentage of hydrocarbons present and to the presence of iron pyrites. In general, the weight of coal will increase, while the quantity of carbon and the heating value will decrease with weathering. The hydrocarbons slowly oxidize with a rise of temperature and there is a slow liberation of gaseous hydrocarbons. Moisture retards this process. An excess of iron pyrites, together with moisture, will usually produce rapid oxidation. This generates excessive heat and may set fire to the coal. This is one of the causes of *spontaneous combustion.* Spontaneous combustion may result from a number of other causes. Coal which has been recently mined, as well as coal with a high percentage of moisture, has a tendency to absorb oxygen from the atmosphere. Poorly ventilated coal will gradually increase in temperature until spontaneous combustion occurs. This is also true of

coal stored with a high initial temperature. Spontaneous combustion may be prevented by proper ventilation or by storing the coal under water. This latter method also reduces the loss in heating value.

5. Analysis

(*a*) *Uses of coal analysis.* Analysis of coal furnishes a commercial basis for the buying and selling of coal. For any given type of boiler, a proximate analysis will allow the selection of the proper coal, taking into account the ratio of carbon to volatiles and also the volume of the combustion chamber space. It is clear that a high volatile coal will not burn efficiently in a boiler having small combustion space. If a certain coal must be used, analysis gives the means of correctly designing the furnace so as to get the maximum efficiency from the coal. It is possible to determine the most important characteristics of the fuel from a proximate analysis. Proximate analysis is ordinarily used in practical engineering work, since the refinement of chemical (ultimate) analysis is not usually required. Moreover an ultimate analysis can only be performed by a skilled chemist.

(*b*) *Proximate analysis.* This test determines roughly the percentages of fixed carbon, ash, moisture, and volatile matter in the coal. A representative sample is weighed and the moisture is driven off by heating it to a temperature of 300° F. for a given time. It is immediately re-weighed and the percentage moisture is calculated from the ratio of the two measurements of the weights. The sample is then heated to a red heat in a closed crucible, in order to drive

off the volatile matter. It is then re-weighed and the percentage of volatile matter is calculated. The carbon is burned up next, by keeping the sample at a white heat and supplying enough air for complete combustion, and the remaining ash is weighed, thus determining the approximate percentage of ash and fixed carbon.

(*c*) *Practical significance of determinations of proximate analysis.*[1]

(1) *Moisture.* This reduces the heat value per pound fired; adds to transportation cost; decreases furnace and boiler efficiency; and in general means the loss of the total heat value of dry fuel of approximately one-tenth per cent for each per cent of moisture.

(2) *Volatile matter.* High percentage of volatile matter results in long flaming coal. Therefore it is difficult to get smokeless and complete combustion except where furnace is specially designed to take care of this. A moderate percentage of volatile matter gives the best efficiency and the highest heating value.

(3) *Ash.* Ash tends to prevent passage of the air and for this reason will not only prevent complete combustion, but will also require more frequent cleaning if present in much quantity. Coal containing 40 per cent ash is valueless in an ordinary furnace. Ash contains about 55 per cent silica, 30 per cent alumina and oxide of iron, 5 to 9 per cent of lime and a small percentage of sulphuric acid. Ordinarily the sulphur and iron are present in the coal as

[1] NOTE. — (*c*) and (*d*) are based on material from Hirschfeld and Barnards "Heat Power Engineering," published by John Wiley & Sons, Inc.

"iron pyrites"; sometimes sulphur itself is present. Iron oxide, together with lime, tend to help the fusion of the silica, thus causing clinker formation. This explains why coals, having a high percentage of sulphur which is usually combined with iron, give such a fusible ash. Ash adds to the expense of generating heat since it requires extra expense in transporting and also extra labor in disposal. It carries coal through the grates along with it and absorbs a certain amount of heat. The percentage of ash ordinarily amounts to from 4 to 25 per cent of the total weight of the coal. The proportion of ash is greater in small coal since it is harder to remove the inert portion.

(*d*) *Heating value.* This is often considered as a part of the proximate analysis. It is important, because the worth of the coal depends to some extent upon its value. Heating value is measured in B.T.U.'s available through the burning of one pound of the coal. The B.T.U. (British thermal unit) is that amount of heat necessary to raise the temperature of one pound of water from 62° F. to 63° F. When coal containing uncombined hydrogen is burned, this hydrogen combines with oxygen to form superheated water vapor. If this vapor passes off without giving up its heat, the heating value of the coal is less than if that heat had been used. In cases where the vapor passes off, the heating value is termed the *lower heating value.* Where the vapor gives up its heat, the heating value is termed the *higher heating value.* It is possible to obtain an approximate determination of the higher and lower heating values from various formulas using values obtained from an ultimate analysis. A rough ap-

proximation may even be obtained from the results of a proximate analysis. However, the only accurate way to find the heating value is by means of a calorimeter. The calorimeter gives the higher heating value, and this is the one which should be used in boiler testing work as it is generally considered the only scientific value.

(*e*) ***Heating value determination.*** The formula used to give an approximation of the heating value of coal as a predetermination from the ultimate analysis is known as Dulong's. Other formulas have been derived, based on Dulong's, but this one, with a slight modification, is the most commonly used. It states that

Heat units in B.T.U. per pound of dry fuel =

$$14{,}600\,C + 62{,}000\left(H - \frac{O}{8}\right) + 4000\,S,$$

where C equals per cent carbon,
H " per cent hydrogen,
O " per cent oxygen,
S " per cent sulphur, all by weight.

As stated above, although this formula is good enough for determining the general characteristics of a fuel, the heating value must be determined by a calorimeter, in computing efficiencies, etc. The " Bomb calorimeter " is most generally used for this. In this type, the fuel is completely burned and the heat generated by such combustion is absorbed by water, the amount of heat being calculated from the increase in the temperature of the water. The Mahler type of " Bomb calorimeter " is considered to be one of the best. In this type the fuel to be tested is put into

a steel bomb filled with compressed oxygen. The oxygen produces very rapid combustion. The fuel is ignited by means of electricity. Allowance is made, of course, for the heat produced by the electric current and the burning of the fuse wire. Great care should be exercised in selecting the sample.

(*f*) *Ultimate analysis.* The ultimate analysis of coal is a chemical analysis which reduces the fuel to its ultimate constituents of carbon, hydrogen, oxygen, nitrogen, sulphur, ash, and moisture. This analysis must be made by a skilled chemist. Although this analysis reduces the fuel to its elementary constituents it does not show how they combine in the fuel. Ultimate analysis is generally given both on a moist and a dry fuel basis. The dry basis is the one in most general use for comparison of data.

6. Firing Coal

(*a*) *Even spread firing.* Coal is spread evenly from the back of the grate and working toward the door. The best thickness depends upon the quality of the coal, its size, the draft and the rate of firing. Best time rate is determined by experiment. Where there is more than one firing door the doors should be fired alternately. This method has the advantage of preventing the whole surface of the fire being blanketed with green coal and the steam is generated more uniformly than if all the doors are fired at one time. More of the volatile matter is burned using this method than if all doors are fired at the same time.

(*b*) *Coking.* In the coking method of firing, fresh coal is

fired at considerable depth at the front of the grate and after it is partly coked, it is pushed back into the furnace. This way of firing gives a bed of incandescent carbon at the back of the furnace, over which the volatile gases must pass and it aids materially in their complete combustion.

(*c*) There are several other methods of firing such as *alternate side firing* in which the fresh coal is first spread on one side of the grate for the whole length, then on the other side, at equal intervals of time; another method is *alternate front and back firing* in which method the coal is alternately fired on the front and then the back halves of the grate instead of on the alternate sides. These methods are supposed to result in better mixture of the hot gases with the hot air and hence in more complete combustion and less smoke. Large combustion space is necessary for these methods of firing; otherwise they are useless.

(*d*) Scotch boilers, as well as all fire tube boilers having but one door per furnace, are usually fired by the even spread system. This system seems to be the most common one for all types of boilers. Water tube boilers having more than one door to each furnace, are sometimes best fired by *alternate side firing*. The coking system is economical and smokeless, provided that the fireman exerts special effort and care. Moreover, all coals cannot be used with this system. In a type of furnace, in which the gases pass horizontally over the fire, the coking system will give the best results.

7. Kinds of Oil

(*a*) Fuel oils are classified according to their base as (1) asphaltum, (2) paraffine. This means that the petroleum

obtained from the well boils down after successive distillations either to asphaltum or paraffine according to its base. There is a third class of petroleum which has olefine as a base. This group of oils comes from Russia and is not used to any extent in this country.

Asphaltum oils come from Texas and California. They vary in color from reddish brown to jet black and are thick and heavy. They are largely used for fuel.

Paraffine oils come from the Appalachian region and the Middle West. They are lighter than the asphaltum oils and are dark brown in color with a greenish tinge. Light oils are obtained from them by distillation. The residue which is left after the third distillation is used as fuel oil. This is small in amount and more expensive than that obtained from asphaltum oils. Fuel oil is obtained from the asphaltum oils after only two distillations and a large residue is left.

(*b*) *Constituents of oils:*

Analysis of 3 representative oils:

	California, Bakersfield [1]	Texas, Beaumont crude [2]	Pennsylvania crude [3]
Per cent carbon	85.0	84.6	84.9
Per cent hydrogen	13.0	10.9	13.7
Per cent oxygen	1.0	2.87	1.4
Per cent nitrogen	0.2	....	....
Per cent sulphur	0.8	1.63	....
Per cent water	1.0	....	....

[1] Authority — Lyon and Hinds.
[2] Authority — U. S. Navy Liquid Fuel Board.
[3] Authority — Booth

(*c*) *Process of fractional distillation.* The petroleum is put into a still after the water and other impurities have been

removed and it is heated to a certain temperature and kept at that temperature until certain of the hydrocarbons have evaporated. These are led off to a condenser where they are again liquefied. The oil which is left is then heated to a higher temperature and the process is repeated. With certain petroleums it is possible to repeat this fractional distillation a number of times. The liquid fuel used for marine purposes, in both boiler furnaces and in internal combustion engines, is produced by fractional distillation in vacuo, the flash point desired and the cold settling point determining the amount of distillation.

8. Physical Properties of Fuel Oils

(*a*) *Color*. The color of the oil is an indication of its base. The oils used for fuel vary in color from light green to jet black. The colors corresponding to the various bases are mentioned above.

(*b*) *Viscosity*. This is a measure of the resistance (within the liquid itself) to flow. It is usually defined as the rate of flow of a certain amount of the oil, through a hole of standard size, at a given temperature. The oil measured is referred either to water or to genuine sperm oil as a standard. The standard temperature is usually taken as 70° F. The higher the numerical viscosity of an oil the slower is its rate of flow. Or in other words, as the oil approaches the rate of flow of water, its viscosity is lower, and it can be pumped and will flow with greater ease. The viscosity of an oil is closely related to, but not exactly proportional to, its specific gravity. As the temperature is increased, there is a very

rapid decrease in the viscosity of most oils. For example, a viscosity test of a California fuel oil, having a flash point of 174° F. and a specific gravity of 16.1° Baumé, showed that when the temperature was increased from 70° F. to 140° F. (doubled), the viscosity decreased from 96 (on the basis of viscosity Engler compared with water at 70° F. equal to 1) to 8, showing that for this oil a 100 per cent increase in temperature resulted in a 1200 per cent decrease in viscosity.

(*c*) *Specific gravity*. The specific gravity or density of an oil is the weight of a certain volume of it as compared to the weight of the same volume of water. It is usually measured with a hydrometer made for this purpose. This instrument consists of a glass bulb whose upper end consists of a graduated stem and whose lower end contains mercury or lead shot to give it weight. When this is allowed to float in a liquid, its level will be such that the weight of the liquid displaced will just equal the weight of the displacing part of the instrument. Hence, the lighter the liquid, the more will be displaced by the hydrometer and the further it will sink. The graduations on the stem measure the amount that it sinks and thus the specific gravity of the oil is found. Density of fuel oil is usually expressed in Baumé's hydrometer scale. The standard temperature for measuring specific gravity of oil is 60° F. The Baumé scale is obtained in the following manner: It is graduated in degrees to accord with the density of a solution of common salt in water. The length of a degree for liquids heavier than water is found by first floating the instrument in pure water. The

5-degree mark is obtained by making a 5 per cent solution of salt and water. The distance between 0 and 5 is divided into five equal parts and the rest of the stem is thus measured off for liquids heavier than water. For liquids lighter than water, the length of each degree is found by floating the hydrometer in a 10 per cent solution of salt and *this level* is marked zero. It is then put into pure water and this point or level is marked 10°. The distance between is divided into 10 equal parts and serves to determine the calibration of the rest of the stem.

From the above, it can be seen that for liquids lighter than water, the Baumé scale will increase from 10 to 70 as the specific gravity decreases from 1 to .70, whereas for liquids heavier than water the Baumé scale will increase from 10 to 70 as the specific gravity increases from 1.074° to 1.933°. The densities of fuel oils range from 11° Baumé to 37 (that is, from a specific gravity of .992 to .838).

(*d*) *Flash point.* The flash point is that temperature at which the oil will give off hydrocarbons which can be ignited. This is one of the most important characteristics of a fuel oil. This is especially the case in reference to safe storage and usage in confined spaces. Fuel oil has been used with a flash point of 75° F., but experiment seems to indicate that 150° F. should be taken as a m'nimum value for the flash point. The standard test in use for determining the flash point is the closed test in which the oil to be tested is heated in a closed cup.

(*e*) *Fire point.* The fire point or burning point is that temperature to which the oil must be heated at which the

vapors above the surface of the oil will burn continuously. The fire point can be determined with the same apparatus as that used to find the flash point. For fuel oil it should be around 215° F.

(*f*) *Critical point.* The critical point is that temperature of the oil which will give the best atomization and combustion. At the critical point, the viscosity will be best for most efficient operations. For most fuel oils this point is reached at a temperature of between 100° and 150° F. (at a pressure of 200 pounds). Oils having a viscosity of about 8 Engler seem to give best results.

(*g*) *Boiling point.* This is the temperature at which boiling will commence, at atmospheric pressure, and the entire liquid will vaporize. This point should be about 500° F.

(*h*) The *chill point* of an oil is the temperature of solidification.

(*i*) *Volatility.* This is a measure of the loss of weight due to evaporation of volatile vapors. It is possible for an oil to gain weight by absorbing oxygen.

(*j*) *Sediment* and water are tested for by adding an equal quantity of benzol to the oil to be tested and whirling them around in a high speed device which will separate the oil by centrifugal force.

9. Heating Value of Fuel Oils

(*a*) The only accurate method of obtaining the heating value is by means of a bomb calorimeter, as in the case of coal.

(*b*) A formula has been devised which gives the heating value, with fair accuracy. It is
For American fuel oils,

$$\text{B.T.U.'s} = 18{,}650 + 40 \text{ (degrees Baumé} - 10).$$[1]

(*c*) Heating values of three representative oils in B.T.U.'s per pound.

California, Bakersfield.....17,600 B.T.U. to 18,926 B.T.U.
Texas, Beaumont, crude....19,060 B.T.U. to 19,654 B.T.U.
Pennsylvania, crude........19,210 B.T.U. to 20,949 B.T.U.

The lower the specific gravity the higher the heating value. A pound of fuel oil usually has a heating value between 18,000 to 22,000 B.T.U.'s.

10. Methods of Atomization

(*a*) *Air.* This method requires the use of air compressors and of steam to operate these. It is sometimes the practice to heat the jet of compressed air.

(*b*) *Steam.* The atomization may be caused by a jet of steam. The steam is sometimes superheated for the purpose of increasing the efficiency of combustion. The principle of operation of steam atomization is the same as that of the injector. Wet steam may cause the burners to go out, and, moreover, this method is wasteful of steam and feed water.

(*c*) *Mechanical.* The oil is greatly compressed and then sprayed through a small orifice. This method is coming

[1] Above formula from Sherman and Knopff, American Chemical Society, Oct., 1908.

into general use, although (*a*) and (*b*) are still used to a considerable extent in the merchant marine. Forced draft blowers are sometimes used in conjunction with the mechanical system. The mechanical system is sometimes called the high pressure system.

11. Object of Atomization

The object is to increase the surface area of the fuel by dividing it into a minute spray of a large number of very small particles. This allows for a very close mixture with the air required for combustion. In air and in steam atomization the oil and the atomizing agent may meet either inside or outside of the atomizer.

12. Essential Requirements for Burning Oil

(*a*) Sufficient heat must be radiated from the refractory material of the furnace so that the combustion will be complete.
(*b*) Atomization must be thorough.
(*c*) The supply of air must be sufficient for complete combustion, but this supply should be limited to a minimum to reduce stack losses.
(*d*) Combustion must be completed before the gases come into contact with the heating surfaces, since otherwise the burner may be extinguished with the resultant danger of a flare back when the burner is re-lighted.

QUESTIONS

1. Name and describe four important classes of coal.
2. Is the coking of coal desirable?

3. What is the effect of sulphur in coal?
4. What does the color of the ash indicate?
5. What effect has weathering on coal?
6. What causes "spontaneous combustion"?
7. What are the uses of a coal analysis?
8. What is the difference between an ultimate and a proximate analysis?
9. Explain the practical significance of the various determinations of a proximate analysis.
10. What is the unit of heating value as used in practical engineering work?
11. How is the heating value of a fuel best determined?
12. What is the purpose of determining the heating value of a fuel?
13. What is meant by the even spread method of firing?
14. Explain several other methods of firing coal.
15. What method is usual in firing Scotch boilers?
16. How are fuel oils classified?
17. What is meant by fractional distillation?
18. Discuss the physical properties of fuel oils, referring to color, viscosity, specific gravity, flash point, fire point, critical point, boiling point, chill point, volatility, and sediment.
19. What is the only accurate method of obtaining the heating value of fuel oils?
20. How does the heating value of fuel oil vary with the specific gravity?
21. What is the average heating value of a pound of fuel oil?
22. What means are employed to atomize the fuel oil and what is the object of atomization?
23. What are four essential requirements for burning oil?

LESSON 13 — COMBUSTION

1. Combustion

This is the chemical combination of oxygen with the carbon, hydrogen, or other burnable substances of the fuel. Heat is evolved in this process.

(*a*) The amount of heat evolved depends upon the kind of fuel used, its chemical constituents, and upon the completeness of combustion.

(*b*) In general, a pound of oil fuel has a higher heating value than a pound of coal, and moreover the efficiency of combustion of oil is higher than that of coal.

2. Determination of Completeness of Combustion; Flue Gas Analysis

(*a*) ***Flue gas analysis*** is the most accurate method of determining the completeness of combustion. This analysis will also give the amount and distribution of the heat losses due to incomplete combustion.

(*b*) *Sampling*. In order that the proper degree of accuracy may be attained, the sample must be representative so that an average value of the flue gas will be obtained. It should be taken in the last pass of the B. & W. boiler and in the uptake of the Scotch or Express boiler. A sample should not be taken when the furnace door is open. A good

method is to take a large sample over several hours and then to take a small sample from this.

(*c*) *The Orsat apparatus* (Fig. 66) is the one most generally uxed for flue gas analysis. The principle upon which this works is to pass the sample of gas through certain chemicals which will absorb the various gases present in the flue gas.

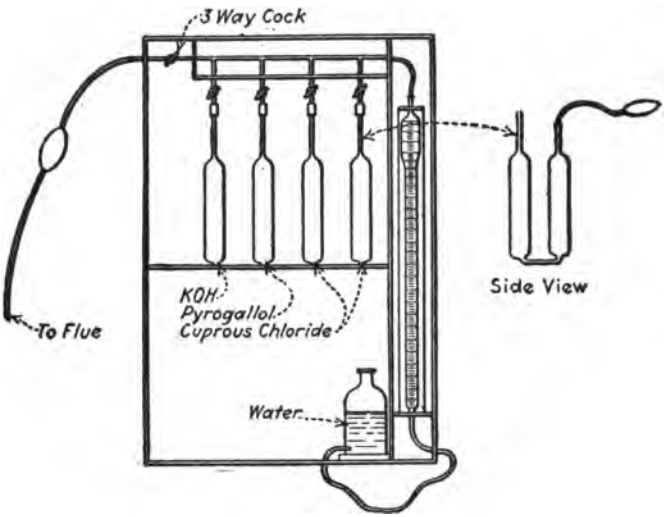


FIG. 66. Sketch of Orsat Apparatus

In this manner, the CO_2 is first taken out, then the O, and finally the CO.

The CO_2 represents perfect combustion;

The CO represents an incomplete combustion;

The O represents pure air present.

CO_2 is the main thing in which we are interested. For this reason, it is sometimes sufficient to use an instrument

which gives the percentage of CO_2 present in the flue gas. These instruments are called CO_2 recorders. They have been tried on board ship but have not met with great success. These instruments automatically draw samples of flue gas from the boilers, pass the gas through a solution of caustic potash, thereby absorbing the carbon dioxide, and at three minute intervals indicate and record by the length of lines on a chart the percentage of CO_2 in the gas. For theoretically complete combustion, the percentage CO_2 by volume is about 20. This is never reached in actual practice. If a CO_2 recorder shows 14 per cent CO_2, a hand test should be run to determine whether the CO and O are sufficiently low. If good operation is obtained with 14 per cent CO_2 and this is constantly recorded, the combustion may then be accepted as O. K. and no further hand tests are required. If, however, the instrument shows a drop to 10 per cent CO_2, the hand apparatus must then be used to determine the fault.

(*d*) *Typical flue gas analyses — Coal; Oil.*

Per cent by volume	Coal	Oil
CO_2	12.9	10.7
O	4.5	5.2
CO	00.5	00.2

(*e*) *What the results of flue gas analysis indicate.*

The percentage of CO_2 is an indication of the economy of consumption but it is not an absolute indication. An increase in the percent of CO_2 is often accompanied by an increase of CO. If, furthermore, the per cent of O is less than 4, this indicates that the increase of CO (incomplete combus-

tion) is due to insufficient air which in turn may be due to too light a draft, too heavy fires or possibly both. Each per cent of CO in flue gas means about 5 per cent loss of fuel.

If the per cent CO_2 should drop and the CO should rise, with the O remaining the same, this also would indicate insufficient air, due to causes given above.

If there is an increase of O with a decrease of CO_2 this would indicate too great an excess of air, possibly due to too much air pressure, holes in fuel bed or both.

If there is an increase of O and CO it indicates that the combustible gases are not thoroughly mixed, or that the flue gas temperature is too low, due to some other reason, such as chilling of the gases below ignition temperature by the heating surfaces of the boiler.

If the per cent of CO_2 is high and there is 4 to 8 per cent of O and any CO is present, this indicates that the rate of combustion is too rapid, resulting in a chilling and consequent incomplete combustion of the gases.

(*f*) *Maximum and minimum percentages.*

In burning coal, with extremely good operation the per cent of CO_2 may run as high as 13½ to 14. As an actual fact it is usually about 9 to 9½ per cent. The O will vary from 4 to 8 per cent while the CO will average about 0.5 per cent with 0.2 per cent as a lower limit. The best results will come with the proper draft, the proper thickness of fuel bed, and proper use of the dampers. In cases where incomplete combustion is due to the construction of the boiler, no change can be effected.

In burning oil, very good operation will give the per cent

CO_2 as high as 13 or 14 per cent. The lower limit is about 10 per cent. The O will vary from 5 to 7 per cent. An average value of CO is 0.2 per cent.

In adding up these percentages it will be noticed that they do not come to 100 per cent. The remainder of the volume of the flue gas is taken as the per cent of nitrogen. If the per cent of nitrogen by difference is greater than 81, the analysis should be repeated since it indicates that an error has been made.

For theoretically comp ete combustion of carbon with exactly the right amount of air, CO_2 only will result and will amount to 20.91 per cent by volume, the remainder being the 79.09 per cent nitrogen. With an excess of air, CO_2 and O will result and the sum of these two for theoretically complete combustion will amount to 20.91 per cent by volume.

The flue gas analysis does not determine the amount of hydrogen or water vapor. The effect of hydrogen is to increase the apparent percentage of nitrogen in the flue gas.

3. Air Requirements

(*a*) *Theoretical.* It is possible to determine by calculation the air necessary to burn one pound of fuel. The theoretical air necessary may be calculated from the formula.

Air (lbs.) for combustion of 1 lb. of fuel =

$$11.6\,C + 34.8\left(H - \frac{O}{8}\right)$$

where C is per cent carbon by weight,

H " " hydrogen by weight,

O " " oxygen by "

(*b*) *Actual.* In practice, the amount of air theoretically necessary is not sufficient for complete combustion. The actual air necessary may be determined from the flue gas analysis, using the following formula:

$$\text{Lbs. of air supplied per lb. of fuel}^{1} = 3.036\left(\frac{N}{CO_2 + CO}\right) \times C$$

where N is the per cent by volume of nitrogen,
CO_2 " " " " " " carbon dioxide,
CO " " " " " " carbon monoxide,
C is the per cent by weight of the carbon which is burned from the fuel and passes up the stack as flue gas.

To find the per cent of carbon which is burned, deduct from the total percentage of carbon, as found in the ultimate analysis, the percentage of unconsumed carbon found in the ash. This latter is the difference between the per cent of ash found by anaylsis and that as determined by a boiler test. (Assume that the entire combustible element in the ash is carbon.)

(*c*) *Comparison between theoretical and actual air requirements, using an actual analysis of coal and oil.* Amounts in pounds air per pound, coal fired; per pound oil supplied.

	Coal	Oil
Theoretical	12	14
Actual	20–25	18

The excess air is the amount over and above that theoretically required. The excess air required with coal may

[1] Note. — See Transactions, A.S.M.E., Vol. 21, 1900, page 94; also B. & W. "Steam."

reach 100 per cent with 50 per cent excess as the lowest possible figure. With oil, 35 per cent excess air is the limit, with a minimum of about 15 per cent. From this it can be seen that there is a great saving in heat with the use of oil, since there is less excess air to be heated and lost up the stack.

4. Combustion (Coal)

(*a*) *Conditions for perfect combustion.*

(1) Proper mixture of the gases of combustion and air must be obtained. The proper design of the furnace, combustion chamber and setting will affect this.

(2) Temperature must be high enough, since a low temperature results in incomplete combustion.

(3) Excess air must be sufficient, otherwise incomplete combustion is sure to result. Too much excess air means loss of sensible heat, while too little means high CO content in the flue gas.

(*b*) *Rate of combustion.* This is the amount of coal burned per square foot of grate surface per hour. When working economically with funnel draught only, the rate is from 15 to 20 lbs. of coal. When working under induced or forced draft, the rate is increased to from 24 to 40 lbs. per square foot of grate surface per hour. The rate of combustion is governed by the coal to be burned and the draft available. It is possible to get even higher rates of combustion with boilers of the " express " type.

(*c*) *Visible indications of proper and improper combustion.* Smoke is the visible result of incomplete combustion. It is caused by the temperature of combustion being too low,

so that the hydrocarbons and coal tar products and carbon particles are not properly burned. The greatest loss is not due to the carbon particles, which are comparatively unimportant, but to the CO which is carried up the stack. This is invisible, but it forms the greatest percentage of the loss, with incomplete combustion. Hence, it can be seen that a clear stack does not always prove that the combustion is complete or that CO is absent. A slight feather of smoke coming from the funnel is better than no smoke at all, if this method is to be used as an indication of proper or improper combustion.

5. Combustion (Oil)

(*a*) *Conditions for perfect combustion.*

(1) *Atomization.* To get complete atomization the proper kind of burner must be used.

(2) *Temperature.* The proper refractory material must be used to get the right furnace temperature.

(3) *Excess Air.* The proper quantity of air must be supplied and at the proper velocity. About as much air as oil must be supplied in order to get thorough mixing before they reach the back of the furnace. The supply of air is regulated by means of air cones, or impeller plates, called air registers or tuyeres into which the burners are set. These registers are set in the furnace front.

(*b*) *Rate of combustion.* This is the weight of oil fuel consumed per cubic foot of combustion space. In the merchant marine this rate is seldom greater than from 15 to 20 lbs. of oil.

(*c*) *Visible indications of proper and improper combustion.* These are nearly the same as for coal. White smoke is the moisture condensed due to a low temperature resulting from an excess of air. If the smoke is black, this is due to too little air and this means incomplete combustion. A grayish haze is an indication that the proper amount of air is being supplied. An indication as to whether the combustion is complete may also be obtained by examining the furnace. The oil flame should be short and of a yellowish white color. Within the furnace, the flame should be nearly invisible and the results of combustion should not be seen. The back wall should be visible, but not distinctly. If it can be seen distinctly and the flame is white, this is an indication of too much air.

6. Advantages of Liquid Fuel

(*a*) More B.T.U.'s in one lb. of oil than in one lb. of coal.

(*b*) Boiler efficiency is higher. No loss through grate or deposit on heating surface. Not as much excess air needed. Five to ten per cent more efficient.

(*c*) Fewer men required. About one-half as many firemen required.

(*d*) Quicker and easier to take aboard.

(*e*) Cleaner, keeps boiler cleaner, fires easier to control.

(*f*) Takes up less space, reduction being about ten per cent.

QUESTIONS

1. Define combustion. What does the amount of heat evolved depend upon?

2. What is the reason for making a flue gas analysis?
3. What precautions must be observed in sampling for a flue gas analysis?
4. Describe the Orsat apparatus.
5. Is a high percentage of CO_2 a positive indication of correct combustion?
6. One pound of pure carbon requires 2.67 pounds of oxygen to completely burn it. This is equivalent to 32 cubic feet of oxygen at 60 degrees Fahrenheit. Air is composed of 20.91 per cent oxygen and 79.09 per cent nitrogen (by volume). What is the actual volume of air required for the complete combustion of a pound of pure carbon?
   Answer 153 cubic feet.
7. Carbon, when chemically united with oxygen of the air, forms carbon dioxide, and this gas will have the same volume as the volume of the oxygen supplied. If exactly enough air is supplied for the theoretically complete combustion of a pound of carbon, what will be the percentage, by volume, of the carbon dioxide formed?
   Answer 20.91 per cent.
8. If 50 per cent excess air is supplied for the combustion of the carbon, what will be the percentage by volume of the carbon dioxide formed? What percentage of oxygen will still remain?
   Answer 13.91 per cent CO_2, 7 per cent oxygen.
9. If 100 per cent excess air is supplied, what percentage of CO_2 will be formed? What percentage of oxygen will remain?
   Answer 10.45 per cent CO_2, 10.45 per cent oxygen.
10. What is the highest theoretical percentage of CO_2 which it is possible to obtain? Answer 20.91 per cent.
11. Is this value ever reached in actual practice?
12. Why is a great excess of air undesirable in burning fuel?
13. If 320 cubic feet of air are necessary for the actual combustion of a pound of coal under natural draft, how much air will

be necessary for the combustion of a ton of this coal, and what will the weight of this air be? (Assume the volume of a pound of air to be 13.1 cubic feet.)

Answer 640,000 cubic feet, 20.61 tons.

14. Name three conditions necessary for the best combustion of coal.
15. What is meant by the "rate of combustion"? Give some average values.
16. What are the visible indications of proper and improper combustion of coal?
17. What are the necessary conditions for the perfect combustion of oil?
18. What are the visible indications of proper and improper combustion of oil?
19. Name five advantages of oil over coal.

LESSON 14 — DEFINITIONS AND CALCULATIONS; EVAPORATION, EFFICIENCY, ETC.

1. Boiler Includes

(*a*) *Furnace*, to make heat available.

(*b*) *Heating surface*, to absorb heat.

Heat is a form of *energy* known as "thermal energy." Boiler transforms energy of coal into energy of steam.

2. Furnace

(*a*) *Grate.* Suspended to allow air to circulate and ashes to drop.

(*b*) *Fuel bed.* Large fuel bed necessary for a continuous combustion of fuel. Coal is here changed from a solid to a gaseous state.

(*c*) *Combustion chamber.* Gaseous carbon must be mixed with air for complete combustion. This takes place in the combustion chamber in the Scotch boiler. There is no definite place for this in the water tube boilers.

3. Heat Transfer. A Result of Temperature Difference

(*a*) *Radiation.* Heat energy is given off by incandescent substances. This transfer occurs in straight lines and does not require air as a conducting medium. Radiating surfaces in a boiler evaporate five times as much water per square foot as other heating surfaces.

(*b*) *Convection.* This transfer of heat occurs in hot or boil-

ing fluids due to the currents set up by temperature differences in different portions of the fluid. The increase of circulation, due to convection currents, breaks up the tendency of the gas and water to form insulating surfaces.

(*c*) *Conduction.* This is the transfer of heat either between adjacent bodies or between adjacent particles of a substance.

4. Formation of Steam

(*a*) *Boiling point.* This is the highest temperature, under a given pressure, to which a iquid may be raised, without undergoing a change in state.

(*b*) *Properties of steam.*

Sensible heat is that heat, which, added to or taken away from a body, causes a change in temperature. Thirty-two degrees Fahrenheit is the point in the steam tables used as a base for measuring sensible heat.

Latent heat of vaporization is that amount of heat which must be added to water (after its temperature has ceased to rise), in order to convert it to steam.

Total heat of dry steam is equal to the sum of the sensible heat plus the latent heat.

If the steam is removed from contact with the water, and heat is added, it is known as *superheated steam.*

Wet steam contains a certain percentage of water by weight.

Dry steam is steam having no water in suspension. It is steam saturated with heat and is sometimes called "*saturated steam.*" It is the steam normally formed in contact with boiling water.

(*c*) *Use of steam tables.* The various properties of steam for any used pressure have been compiled in charts and "steam tables," and from these tables it is possible to find out for any given pressure the corresponding temperature, the density, the sensible heat, the latent heat of evaporation, the total heat of steam and various other required properties. In figuring the heat in a pound of steam, it is necessary to use absolute pressures (gauge plus atmospheric).

The following problems and formulas illustrate a few of the uses of the steam tables:

For dry steam:

$$H = h + L,$$

where H is total heat,
h is sensible heat,
L is latent heat.

These values can all be obtained from the steam tables for any desired pressure.

For wet steam:

$$H' = h + QL,$$

where H' is total heat (less than in case of dry steam),
Q is quality of steam.

For superheated steam:

$$H'' = h + QL + \text{Sp. Heat}\,(T_s - T_p)$$

where T_s is the absolute temperature of superheated steam,
T_p is the absolute temperature at given pressure,
Sp. Heat is the mean specific heat of superheated steam at the pressure and temperature of test. For rough calculations it may be taken as 0.47 for low degrees of superheat, and 0.5 for high values.

Problem No. 1. To find the total heat of wet steam, of 97 per cent quality, at gauge pressure of 150 lbs. per square inch. (Assume standard atmospheric conditions.)

From Steam Tables:

$$h \text{ (at 164.7 lbs.)} = 338.2 \text{ B.T.U.'s},$$
$$L \text{ (" 164.7 ")} = 856 \quad \text{"}$$

Hence: $H = 338.2 + (856 \times 0.97) = 1168$ B.T.U's.

Problem No. 2. To find the total heat of superheated steam at gauge pressure of 150 lbs. and temperature of 425° superheat. (Take atmospheric pressure as 14.7.)

$$\text{Absolute pressure} = 150 + 14.7 = 164.7,$$
$$T_s = 425 + 460 = 885°,$$
$$\text{(from steam tables)} \quad T_p = 366 + 460 = 826°.$$
$$\text{Assume Sp. Heat} = 0.5.$$

Hence: $H'' = 338.2 + 856 + 0.5(885 - 826) = 1224.5$ B.T.U.'s.

5. Evaporation

(*a*) *Equivalent evaporation.* This is the changing of water to steam, from and at 212° F., at atmospheric pressure. In order to change one pound of feed water at 212° F. to steam at 212° F., 970.4 B.T.U.'s are necessary. The equivalent evaporation is used as the basis of comparison in determining the output and efficiency of any boiler.

(*b*) *Factor of evaporation.* In order to reduce actual evaporation to a standard basis (i.e., the standard condition of evaporation or the "equivalent evaporation") it must be divided by a number called the "Factor of Evaporation." Since the heat actually required to evaporate one pound of

water will always be more than the equivalent evaporation, the factor of evaporation will always be greater than one.

The actual evaporation will be measured by the heat per pound required to raise the temperature of the feed water from its original value to that temperature corresponding to the steam pressure of the test. The equivalent evaporation will be measured by the heat required to change *from* feed water, per pound, at 212° F. to steam *at* 212° F. at atmospheric pressure. The factor of evaporation may be determined from the steam tables, by means of the following formula:

$$\text{Factor of evap.} = \frac{H - (t_f - 32)}{970.4}$$

where H is the total heat of steam,

t_f is temperature of feed.

For example, if 1200 B.T.U.'s are actually required to evaporate a pound of feed water under the conditions of test, whereas 970.4 B.T.U.'s are needed under standard conditions, then

$$\text{Factor of evaporation} = \frac{1200}{970.4} = 1.24.$$

(*c*) *Evaporation per pound of coal.* The evaporation per pound of dry coal may be based on the actual evaporation or it may be based on the equivalent evaporation.

When based on actual evaporation, from 8 to 10 lbs. of water may be evaporated per pound of coal.

When based on equivalent evaporation, from 10 to 12 lbs. of water may be evaporated per pound of coal.

6. Boiler Horsepower

(*a*) ***Manufacturers' rated horsepower.*** Manufacturers rate their boilers on so many square feet of heating surface per boiler horsepower.

For Scotch boilers allow from 6–8 sq. ft. per rated horsepower.

For water tube boilers allow 9–10 sq. ft. per rated horsepower.

Thus, the manufacturers, in order to rate the boiler (manufacturers' rated H.P.) divide the total square feet of heating surface by 6 to 8 in the case of a Scotch boiler, or by 9 to 10 in the case of a water tube boiler. There is no relation between manufacturers' rated H.P. and developed H.P.

(*b*) ***True boiler horsepower.*** This is a measure of the capacity of the boiler to evaporate water into steam. In order to exactly define the unit of true boiler H.P., the conditions are taken on a standard basis. Thus, one boiler horsepower is defined as the capacity of the boiler to evaporate 34.5 lbs. of water per hour into dry steam *from* water at 212° F. to steam *at* 212° F. This value is held to be the equivalent of the evaporation of 30 lbs. of water at 100° F. into dry steam at 70 lbs. per square inch above atmosphere. The method of obtaining the value of 34.5 lbs. is as follows: Using a table, or the formula given above, the factor of evaporation at feed temperature of 100° F. and gauge pressure of 70 lbs. is found to be 1.149. Multiplying the actual weight of water evaporated per hour, 30 lbs., by this factor, the weight of water evaporated from and at 212° F. is obtained and this is found to be 34.5 (approximately).

Hence a boiler horsepower = $34.5 \times 970.4 = 33,479$ B.T.U.'s per hour.

(*c*) *Developed horsepower:*

$$\text{Developed H.P.} = \frac{\text{Equivalent evaporation}}{34.5}.$$

Thus, for example: If a boiler evaporated, under actual test, 1200 lbs. of water per hour, from feed at 150° F. to steam at 200 lbs. gauge pressure, then

$$\text{Factor of evap.} = \frac{H - (t_f - 32)}{970.4} = \frac{1199.2 - (150 - 32)}{970.4}$$
$$= 1.114.$$

Equivalent evaporation = $1200 \times 1.114 = 1336.8$.

$$\text{Developed horsepower} = \frac{1336.8}{34.5} = 38.7 \text{ H.P.}$$

(*d*) Per cent rating at which boiler is operated:

$$\text{Per cent rating} = \frac{\text{Developed horsepower}}{\text{Manufacturers' rated horsepower}}$$

(*e*) ***Relation between engine horsepower and boiler horsepower.*** There is absolutely no relation between engine horsepower and boiler horsepower. Engine horsepower is a measure of work per unit of time, whereas boiler horsepower is a measure of the capacity of the boiler to evaporate a certain amount of feed water. In spite of this fact, it has been the practice, in certain cases, to refer to the boiler horsepower as being the same as that developed by the engines getting steam from them.

7. Efficiency

(*a*) ***Combined efficiency of boiler, furnace and grate.***

Boiler input (in B.T.U.'s) = lbs. coal per hour times heating value per pound of coal.

Boiler output (in B.T.U.'s) = lbs. of steam generated per hour times the heat energy of one lb. of steam,

Hence, boiler efficiency =

$$\frac{\text{lbs. } H_2O \text{ per hr.} \times [H - (t_f - 32)]}{\text{lbs. coal per hr.} \times \text{heating value of 1 lb. coal}}$$

(*b*) Grate efficiency $= \dfrac{\text{Combustible actually burned}}{\text{Combustible fired}}$.

This value may be obtained by test, but ordinarily it is calculated by dividing the boiler and furnace efficiency into the combined or over-all efficiency.

(*c*) Boiler and furnace efficiency

$$= \frac{\text{Steam generated}}{\text{Combustible fired}}$$

$$= \frac{\text{Heat absorbed per lb. of combustible}}{\text{Calorific value of one lb. of combustible}}$$

"Combustible burned" refers to dry coal, minus the ash and refuse taken from the ash pit.

Boiler and furnace efficiencies cannot be separated, and moreover this is not necessary. When the efficiency of a boiler is given, this usually refers to "Boiler and Furnace Efficiency."

(*d*) ***Boiler losses.***

	Average value
(1) Loss due to moisture in coal (evaporation)	0.11 per cent

(2) Loss due to moisture from burning of hydrogen..........................	3.6 per cent
(3) Loss due to heat carried away in dry chimney gas....................	10.16 per cent
(4) Loss due to incomplete combustion of carbon..........................	0.5 per cent
(5) Loss due to unconsumed combustible in ash..........................	1.85 per cent
(6) Loss due to radiation and unaccounted for loss..........................	9.23 per cent

This leaves 75 per cent as the heat absorbed by the boiler, which is a fair value. The calculation of the above losses, to determine what becomes of all the heat supplied is called a *heat balance.*

(*e*) *Some values of boiler efficiency obtained in practice.*

Coal:

15 lbs./sq. ft. of grate surface..........	74.4 per cent
24 " " " " "	74.0 per cent
35 " " " " "	72.8 per cent
41 " " " " "	72.0 per cent
43 " " " " "	69.2 per cent
70 " " " " "	63.3 per cent

Oil:

16 lbs./cu. ft. of combustion space......	80.2 per cent
28 " " " " "	79.5 per cent
37 " " " " "	72.7 per cent

(*f*) *Methods of reducing heat lost up the stack.*

(1) Use of hot gases to heat air used for combustion.

(2) Use of economizer to heat feed water.

QUESTIONS

1. Explain the three means of heat transfer.
2. What is the "boiling point" of a liquid?
3. What is "sensible heat"?
4. Define "latent heat of vaporization."
5. Define "dry steam"; "wet steam"; "saturated steam."
6. What is the "total heat" of dry steam equal to?
7. What is "superheated steam"?
8. Find the total heat of wet steam, of 98 per cent quality, at gauge pressure of 160.3 pounds per square inch.
9. What is the total heat of wet steam, of 99 per cent quality, at absolute pressure of 200 pounds per square inch.
10. The total heat contained in a pound of steam is 1171.89 B.T.U's. The absolute pressure is 190 pounds. Find the quality of the steam. Answer 97 per cent.
11. How much heat is required to heat boiler feed water from 60 degrees Fahrenheit to vaporization at boiler pressure of 200 pounds per square inch gauge? Assume that barometer reads 29.9 inches which is equal to 14.7 pounds. Answer 333.2 B.T.U.'s.
12. Find the total heat of superheated steam at absolute pressure of 180 pounds and temperature of 430 degrees superheat. Answer 1224.85 B.T.U.'s.
13. What is meant by "equivalent evaporation"?
14. Define the term "factor of evaporation."
15. What is "actual evaporation"?
16. How many pounds of water may be evaporated per pound of dry coal, based on actual evaporation? How many when based on equivalent evaporation?
17. Define "manufacturers rated horsepower."
18. Explain what is meant by "true boiler horsepower."
19. What is "developed horsepower."?
20. Define "percentage rating" at which boiler is operated.

21. Define "boiler efficiency."
22. Define "grate efficiency."
23. Define "boiler and furnace efficiency."
24. Name six boiler losses.
25. What is a fair value for percentage of heat absorbed by the boiler?
26. What is meant by a "heat balance"?
27. What boiler loss is the greatest? Name two methods for reducing this loss.

TABLES

TABLE I. PROPERTIES OF SATURATED STEAM

p	t	v	h	L	$H = h + L$	P
Absolute Pressure in Pounds Per Square Inch	Temperature of Boiling Point in Degrees Fahr.	Specific Volume, Cubic Feet Per Pound	Sensible Heat of the Liquid Above 32° F. in B.T.U.'s	Latent Heat of Evaporation in B.T.U.'s	Total Heat of Steam above 32° F. in B.T.U.'s	Gauge Pressure Based on a Barometric Pressure of 14.7 Pounds Per Sq. In.
14.7	212.0	26.79	180.0	970.4	1150.4	0.0
20	228.0	20.08	196.1	960.0	1156.2	5.3
25	240.1	16.30	208.4	952.0	1160.4	10.3
30	250.3	13.74	218.8	945.1	1163.9	15.3
35	259.3	11.89	227.9	938.9	1166.8	20.3
40	267.3	10.49	236.1	933.3	1169.4	25.3
45	274.5	9.39	243.4	928.2	1171.6	30.3
50	281.0	8.51	250.1	923.5	1173.6	35.3
55	287.1	7.78	256.3	919.0	1175.4	40.3
60	292.7	7.17	262.1	914.9	1177.0	45.3
65	298.0	6.65	267.5	911.0	1178.5	50.3
70	302.9	6.20	272.6	907.2	1179.8	55.3
75	307.6	5.81	277.4	903.7	1181.1	60.3
80	312.0	5.47	282.0	900.3	1182.3	65.3
85	316.3	5.16	286.3	897.1	1183.4	70.3
90	320.3	4.89	290.5	893.9	1184.4	75.3
95	324.1	4.65	294.5	890.9	1185.4	80.3
100	327.8	4.429	298.3	888.0	1186.3	85.3
105	331.4	4.230	302.0	885.2	1187.2	90.3
110	334.8	4.047	305.5	882.5	1188.0	95.3
115	338.1	3.880	309.0	879.8	1188.8	100.3
120	341.3	3.726	312.3	877.2	1189.6	105.3
125	344.4	3.583	315.5	874.7	1190.3	110.3
130	347.4	3.452	318.6	872.3	1191.0	115.3
135	350.3	3.331	321.7	869.9	1191.6	120.3
140	353.1	3.219	324.6	867.6	1192.2	125.3
145	355.8	3.112	327.4	865.4	1192.8	130.3
150	358.5	3.012	330.2	863.2	1193.4	135.3
155	361.0	2.920	332.9	861.0	1194.0	140.3
160	363.6	2.834	335.6	858.8	1194.5	145.3
165	366.0	2.753	338.2	856.8	1195.0	150.3
170	368.5	2.675	340.7	854.7	1195.4	155.3
175	370.8	2.602	343.2	852.7	1195.9	160.3
180	373.1	2.533	345.6	850.8	1196.4	165.3
185	375.4	2.468	348.0	848.4	1196.8	170.3
190	377.6	2.406	350.4	846.9	1197.3	175.3
195	379.8	2.346	352.7	845.0	1197.7	180.3

TABLE I (*Continued*)

p	t	v	h	L	$H = h + L$	P
Absolute Pressure in Pounds per Square Inch	Temperature of Boiling Point in Degrees Fahr.	Specific Volume, Cubic-Feet Per pound	Sensible Heat of The Liquid above 32° F. in B.T.U.'s	Latent Heat of Evaporation in B.T.U.'s	Total Heat of Steam above 32°F. in B.T.U.'s	Gauge Pressure Based on a Barometric Pressure of 14.7 Pounds Per Sq. in.
200	381.9	2.290	354.9	843.2	1198.1	185.3
205	384.0	2.237	357.1	841.4	1198.5	190.3
210	386.0	2.187	359.2	839.6	1198.8	195.3
215	388.0	2.138	361.4	837.9	1199.2	200.3
220	389.9	2.091	363.4	836.2	1199.6	205.3
225	391.9	2.046	365.5	834.4	1199.9	210.3
230	393.8	2.004	367.5	832.8	1200.2	215.3
235	395.6	1.964	369.4	831.1	1200.6	220.3
240	397.4	1.924	371.4	829.5	1200.9	225.3
245	399.3	1.887	373.3	827.9	1201.2	230.3
250	401.1	1.850	375.2	826.3	1201.5	235.3
260	404.5	1.782	378.9	823.1	1202.1	245.3
270	407.9	1.718	382.5	820.1	1202.6	255.3
280	411.2	1.658	386.0	817.1	1203.1	265.3
290	414.4	1.602	389.4	814.2	1203.6	275.3
300	417.5	1.551	392.7	811.3	1204.1	285.3
310	420.5	1.502	395.9	808.5	1204.5	295.3
320	423.4	1.456	399.1	805.8	1204.9	305.3

For accurate work, change the corrected barometer reading into pounds per square inch, add this to the gauge reading, and find desired steam properties by first referring to Column 1.
For rough work, read gauge pressure and refer to last column.

NOTE: — Reproduced, by permission, from Marks & Davis' Steam Tables and Diagrams (Longmans Green & Co.).

TABLE 2. PROPERTIES OF SATURATED STEAM

From 29.8 in. Vacuum to Atmospheric Pressure

		p	t	v	h	H
Vacuum in Inches of Mercury Referred to a 30″ Bar (Mercury at 58.4° F.)	Absolute Pressure in Inches of Mercury at 32° F.	Absolute Pressure in Pounds Per Sq. Inch	Temperature of Boiling Point in Degrees Fahr.	Specific Volume in Cubic Feet Per Pound	Sensible Heat of the Liquid above 32° F. in B.T.U.'s	Total Heat of Steam above 32° F. in B.T.U.'s
29.8	0.1994	0.0977	34.42	3004.0	2.43	1074.4
29.7	0.2991	0.1465	44.91	2040.	12.97	1079.2
29.6	0.3989	0.1954	52.60	1554.	20.68	1082.5
29.5	0.4986	0.2443	58.77	1259.	26.85	1085.3
29.4	0.598	0.293	63.86	1063.	31.93	1087.5
29.3	0.698	0.342	68.33	918.	36.40	1089.6
29.2	0.797	0.390	72.27	810.	40.32	1091.3
29.1	0.897	0.439	75.84	724.	43.88	1092.9
29.0	0.997	0.488	79.07	657.	47.11	1094.3
28.9	1.097	0.537	81.97	599.3	50.00	1095.6
28.8	1.196	0.586	84.61	552.5	52.63	1096.8
28.7	1.296	0.635	87.10	512.2	55.11	1097.9
28.6	1.396	0.684	89.47	476.9	57.47	1098.9
28.5	1.495	0.732	91.70	446.2	59.70	1100.0
28.4	1.595	0.781	93.79	419.6	61.78	1100.9
28.3	1.695	0.830	95.78	396.0	63.77	1101.7
28.2	1.795	0.879	97.67	375.0	65.65	1102.6
28.1	1.894	0.928	99.45	356.4	67.42	1103.4
28.0	1.994	0.977	101.15	339.6	69.12	1104.1
27.9	2.094	1.026	102.79	324.1	70.75	1104.8
27.8	2.194	1.075	104.35	310.3	72.31	1105.5
27.7	2.293	1.123	105.85	297.6	73.80	1106.1
27.6	2.393	1.172	107.30	286.0	75.25	1106.8
27.5	2.493	1.221	108.70	275.2	76.64	1107.4
27.4	2.592	1.270	110.05	265.1	77.99	1108.0
27.3	2.692	1.319	111.36	255.8	79.30	1108.6
27.2	2.792	1.368	112.63	247.2	80.56	1109.1
27.1	2.892	1.417	113.87	239.2	81.80	1109.6
27.0	2.991	1.465	115.06	231.9	82.98	1110.2

TABLE 2 (*Continued*)

		p	*t*	*v*	*h*	*H*
Vacuum in Inches of Mercury Referred to a 30″ Bar (Mercury at 58.4° F.)	Absolute Pressure in Inches of Mercury at 32° F.	Absolute Pressure in Pounds Per Sq. In.	Temperature of Boiling Point in Degrees Fahr.	Specific Volume in Cubic Feet Per Pound	Sensible Heat of the Liquid above 32° F. in B.T.U.'s	Total Heat of Steam above 32° F. in B.T.U.'s
26.9	3.091	1.514	116.20	224.6	84.12	1110.7
26.8	3.191	1.563	117.32	218.0	85.14	1111.2
26.7	3.291	1.612	118.42	211.7	86.33	1111.7
26.6	3.390	1.661	119.50	205.8	87.41	1112.2
26.5	3.490	1.710	120.55	200.2	88.46	1112.6
26.4	3.590	1.759	121.55	195.1	89.46	1113.0
26.3	3.690	1.808	122.54	190.1	90.44	1113.4
26.2	3.789	1.856	123.51	185.5	91.41	1113.9
26.1	3.889	1.905	124.45	181.0	92.35	1114.3
26.0	3.989	1.954	125.38	176.7	93.28	1114.7
25.9	4.088	2.003	126.28	172.7	94.18	1114.9
25.8	4.188	2.052	127.17	168.9	95.06	1115.3
25.7	4.288	2.101	128.04	165.1	95.93	1115.7
25.6	4.388	2.150	128.90	161.5	96.79	1116.1
25.5	4.487	2.198	129.75	158.1	97.64	1116.5
25.4	4.58	2.24	130.59	154.8	98.48	1116.9
25.3	4.68	2.29	131.42	151.6	99.30	1117.3
25.2	4.78	2.34	132.21	148.6	100.11	1117.7
25.1	4.88	2.39	133.00	145.8	100.88	1118.0
25.0	4.98	2.44	133.77	143.0	101.65	1118.3
24.0	5.98	2.93	140.64	129.0	108.51	1121.3
23.0	6.98	3.42	146.78	104.5	114.64	1123.9
22.0	7.97	3.90	152.16	92.3	120.02	1126.2
21.0	8.97	4.39	157.00	82.6	124.86	1128.2
20.0	9.97	4.88	161.42	74.8	129.28	1130.1
19.0	10.97	5.37	165.42	68.5	133.28	1131.8
18.0	11.96	5.86	169.14	63.1	137.00	1133.4
17.0	12.96	6.35	172.63	58.6	140.50	1134.8
16.0	13.96	6.84	175.93	54.6	143.80	1136.1
15.0	14.95	7.32	179.03	51.17	146.91	1137.4

TABLE 2 (*Continued*)

		p	t	v	h	H
Vacuum in Inches of Mercury Referred to a 30″ Bar (Mercury at 58.4° F.)	Absolute Pressure in Inches of Mercury at 32° F.	Absolute Pressure in Pounds Per Sq. In.	Temperature of Boiling Point in Degrees Fahr.	Specific Volume in Cubic Feet Per Pound	Sensible Heat of the Liquid above 32° F. in B.T.U.'s	Total Heat of Steam above 32° F. in B.T.U.'s
14.0	15.95	7.81	181.92	49.03	149.80	1138.6
13.0	16.95	8.30	184.68	45.55	152.57	1139.7
12.0	17.95	8.79	187.31	43.18	155.21	1140.7
11.0	18.94	9.28	189.83	41.05	157.73	1141.7
10.0	19.94	9.77	192.23	39.13	160.14	1142.3
9.0	20.94	10.26	194.52	37.40	162.44	1143.6
8.0	21.94	10.75	196.73	35.79	164.68	1144.5
7.0	22.93	11.23	198.87	34.33	166.81	1145.4
6.0	23.93	11.72	200.94	33.00	168.88	1146.3
5.0	24.93	12.21	202.92	31.76	170.89	1147.0
4.0	25.92	12.70	204.85	30.62	172.81	1147.6
3.0	26.92	13.19	206.71	29.55	174.68	1148.4
2.0	27.92	13.68	208.52	28.57	176.50	1149.1
1.0	28.92	14.17	210.28	27.66	178.27	1149.7
0.0	29.92	14.67	212.00	26.79	180.00	1150.4

Zero vacuum is atmospheric pressure or 14.7 lbs. absolute pressure.
For accurate work, subtract the vacuum in inches of mercury from the corrected barometer reading and find desired steam properties by first referring to Column 2.

For rough work, read vacuum gauge and refer to Column 1.

NOTE: — This table is adapted from "Steam Tables for Condenser Work" by the kind permission of the Wheeler Condenser & Engineering Company.

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